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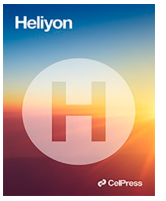

Research article

Reframing the wicked problem of pre-harvest burning: A case study of Thailand's sugarcane

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ABSTRACT

Pre-harvest sugarcane burning persists in many countries though there are policies prohibiting the practice. As problems related to sugarcane harvesting are complex, a thorough understanding of the problems for policy formulation is required. The objective of this study was to reanalyze or reframe problems of sugarcane harvesting and pre-harvest sugarcane burning. Concepts of wicked problems, practical reasoning and policy reframing were applied. The study used a participatory modeling approach to illustrate the case of Thailand. Wickedness was shown by complexity and uncertainties of factors intertwining with values related to adoption of harvesting methods; green mechanical, green manual and burnt manual. As timeliness of harvest was the top priority, the burnt method was considered more efficient. It was easier, faster, cheaper and more suitable under unfavorable circumstances for the green methods. The policy to reduce burnt-harvested sugarcane was not so effective and also led to the undesired 'green but unclean' method. To frame harvesting problems based on emissions of fine particulates ($PM_{2.5}$) from sugarcane burning was not a good choice. Incomplete problem sense-making and poor problem frame were indicated. Most farmers were unable to associate sugarcane burning with environmental problems of $PM_{2.5}$ (and also global warming/climate change) and livelihood impacts. Nevertheless, a larger concern over climate variations was perceived by a majority of farmers. Farmers who adapted relied primarily on green harvesting and the use of residues as trash blankets. Through policy reframing, inefficient green harvesting was seen as a better frame. The new frame enabled farmers linking agricultural practices to sustainability of environment, productivity and livelihoods in the context of climate change. Using participatory modeling for reframing policy problems in general and wicked problems in particular was shown to be powerful and contributing to originality.

1. Introduction

The global sugarcane and sugar/ethanol industry has played an important role in economic viability since the early capitalist expansion [1]. However, facing cycles of undersupply/oversupply, price fluctuations, high competitiveness and environmental concerns during the past decades, the industry seeks innovation and transformation [2].

Sugarcane, grown worldwide as food and energy plant, is a key feedstock of biomass for bio-economy [3]. However, sugarcane production has its own set of impacts on the different dimensions of sustainability for instance; environment, economics and society [4–6]. Challenges to environmental sustainability are particularly related to land use change, water consumption, and air pollution

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[7]. The latter problem is largely recognized as a result of pre-harvest burning is still being practiced [8]. Impacts of sugarcane burning on human and environmental health have been thoroughly documented [9]. As greenhouse gases are among pollutants generated from sugarcane burning [10], climate change is of concern. There are also reports indicating the existence of policies addressing the burning issue of major sugarcane producing countries such as Australia, Brazil, India, Mexico, and Thailand [11–15]. Nevertheless, the problem persists. This may pose a challenge to Net-Zero emissions pledged by many major sugarcane producing countries.

Sugarcane burning is one of harvesting problems. Nevertheless, central to the harvest and harvesting problems are the harvesting methods [16]. In general, there are two principal methods of sugarcane harvesting; green and burnt. The former is performed by manual cutting or the use of mechanical harvesters while the latter requires burning sugarcane fields before manual cutting. Fresh and burnt harvested sugarcane is obtained by green harvesting method and burnt harvesting method respectively. Notes must be taken that 'green' in this case refers to fresh or unburnt sugarcane, but not to sustainable practices. There are sufficient reports indicating environmental problems from sugarcane burning [17–19]. Although causes, effects and policy solutions are indicated by these reports, root causes are not addressed. For instance, mechanical harvesting with financial assistance from the government is recommended, but problems about modes of engagement and biophysical barriers to mechanization are unaddressed [20]. Ineffectiveness of policies solving the burning problem of agricultural residues is indicated [13]. The authors also raise the question of why the problem persists and suggest reconceptualizing the problem through a systems perspective. Nevertheless, empirical case studies relevant to this issue are scarce.

It is interesting that sugarcane burning has been perceived as a problem for over decades, however, the questions of how it is understood (problematic) and why it is difficult to be solved (intractable) have rarely been addressed. This was the critical research question of this study. There are many factors related to sugarcane harvesting in Thailand. Examples are those related to productivity, physical conditions of sugarcane fields, harvesting machines and equipment, transport vehicles, labor, weather, harvesting scheduling, queuing for delivery, and milling [21]. Complex factors related to sugarcane harvesting are also reported in India and Fiji [13,22]. Moreover, adopting different agricultural practices by farmers is shown to associate with different values, represented as desired livelihood outcomes [23]. A combination of multiple facts and values characterizes a very complex problem called 'wicked problem' [24].

This study has a key objective to reanalyze problems of sugarcane harvesting and related policy framing in which pre-harvest burning is one among those problems. The paper applied three key concepts; wicked problems, practical reasoning and policy reframing to re-analyze the sugarcane harvesting problems. The concept of wicked problems is applicable as an analytical tool to explore the nature of the problems and the effectiveness of solutions. The concept of practical reasoning allows one to understand farmers' reasons to adopt a given harvesting method but resist others (if any). Finally, the concept of reframing which is regarded as both theory and method [25], is useful to advance the concept and guide methodology in handling wicked problems. Reframing policy problems is recommended to perform first in dealing with wicked problems [26,27]. Concerning with the relevant methodology, Hoppe [28] proposed the reframing protocol based on problem structuring. As wicked problems are ill-structured (difficult to be defined and guide solutions), giving a structure to the problem is to reduce wickedness [29]. However, there is scarce research applying a bottom-up approach encouraging participation of multi-stakeholders, though engagement is very important in tackling wicked problems [30]. Combining the method of Hoppe with participatory modeling yields a new method for reframing. In addition, as a difference in values can contribute to wickedness [26], integrating the concept of sustainable livelihoods (as values) extends the concept of wicked problems and contributes another novelty. Therefore, the study contributes originality of both conceptualization and methodology dealing with policy problems in general and those wicked ones in particular. The case of Thailand was explored as it is one among the largest sugarcane/sugar/ethanol producing countries where the harvesting problems are existing, perceived and a target for policy attention. It was shown to be justified as an example of empirical cases.

2. Literature review

2.1. Pre-harvest burning of sugarcane

There are two types of burning in relation to sugarcane production, 1) pre-harvest burning to reduce leaves and tops and allow easy cutting and 2) burning of trash after harvesting to reduce inflammable materials and make certain cultivation practices (e.g., tillage and fertilizer application) convenient. However, pre-harvest burning is much more observed; it can remove up to 80 % of the cane trash (leaves and tops). It is easy, fast and cost saving, and is thus a widely adopted practice [31].

Concerning environmental problems, there are studies indicating pollutants derived from sugarcane burning including carbon dioxide, carbon monoxide, methane, particulate matter, polycyclic aromatic hydrocarbon, volatile organic compound and nitrogen oxide [32]. Exposures to these pollutants cause respiratory problems especially asthma [33].

Effects of pre-harvest sugarcane burning may vary depending on severity, soil texture and soil type. Soil fertility may be reduced by burning resulting in a decrease of soil organic matter, soil carbon, total organic nitrogen, carbon/nitrogen ratio and microbial activities [34]. Compared to green sugarcane harvesting, burnt harvesting results in a significant decrease of soil organic carbon and microbial activity [35]. Pre-harvest burning does not affect yield of sugarcane in a short period [36]. However, in a longer period, green harvesting and trash blanketing significantly increase yield [37,38].

2.2. Wicked problems

Wicked problems, opposite to 'tame problems', are complex, intractable, open-ended and unpredictable [39]. The concept of

wicked problems was introduced by Rittel and Webber [40] who proposed that most complex social problems were difficult to be solved by the rational-technical approaches. Tame problems are easily fixed when objectives are clear and methods are efficient. But, wicked problems are confounded by complexity, uncertainties, and different values of stakeholders [41]. A wicked problem is characterized as being difficult to define, without stopping rule, no definitive and clear solutions, having irreversible consequences, and being a symptom of another problem [42]. Examples of wicked problems are climate change and pandemic of COVID-19 [43,44]. The way wicked problems are difficult to be defined and solved, indicates that they are ill-structured [45]. Since wicked problems are associated with multiple stakeholders having different facts and values, there is possibly a distinction of explanations to the problems [26]. These problem explanations or definitions are the key structure of problem frames [46].

2.3. Practical reasoning

Practical reasoning is a claim or conclusion to support an argument of what is decided to do or not to do [47]. It occurs in everyday life and politics as people make decisions, have intentions and take actions [48]. In response to the problems in which decisions, intentions and actions are needed, practical reasoning is exercised [49]. A collection of premises including goal, means-goal, circumstances, values and cost-benefit structures the claim [48]. A claim or argument scheme proposed by the proponent can be challenged by the opponent with other premises [50]. Thus, practical reasoning is an open-ended problem but with limited solutions [51]. However, among limited plans and actions to a problem, values play an important role in decision making [52]. Justifying a choice of actions motivated by goals and goal-attached values is applied in value-based argumentation [53]. Practical reasoning in argumentation can be used to frame and reframe policy problems [50].

2.4. Policy reframing

Frames, framing and reframing have their foundations from research in frame analysis [54] Frame analysis is applied in research fields such as policy studies, communication and social movements [55]. A frame is an interpretive schema, used to understand and construct a meaning of the reality of a policy problem [56]. Frames are shaped by interests, personal identities and worldviews [57]. As frames are subject to interpretation, a policy problem may be framed in different ways by policy actors resulting in competing frames in the policymaking process [25]. Therefore, frames are purposeful and politically powerful. It is a fact that only a certain aspect of a problem situation is selected, highlighted and pushed forward to influence perceptions and responses while other aspects are ignored [58]. This dynamic and politically influenced process is called framing by which the output, a policy frame is constructed [57].

Reframing is one among recommended solutions in dealing with wicked problems [59,60]. The concept of frame reflection is defined as the way policy actors reviewing the existing policy frames and calling for frame shifts or reframing [61]. It is aimed at solving policy controversies in which a conflict of problem definitions prevails. Through reframing, competitive frames of interest will have a chance to be represented for the problem. However, framing/reframing is an important policy process but under-represented [25]. The problem structuring technique suggested by Hoppe is an example of policy framing/reframing [28]. The method includes problem sense-making, problem exploration and categorization, problem decomposition, and selection of a choice of problem definition.

3. Materials and methods

The study was part of a research project, 'Gap and coherence analysis of policies on yield improvement, cost reduction and maintaining stability of sugarcane price'. To reanalyze policy problems related to sugarcane harvesting and pre-harvest burning, determination of gaps and incoherence of the policy to reduce burnt harvested sugarcane was required for the two processes of policy reframing; problem sense-making and problem exploration and categorization. Thus, the framework for this study integrates concepts and methods for policy gap and coherence analysis and reframing. The coherence analysis framework developed by Nilsson et al. [62]

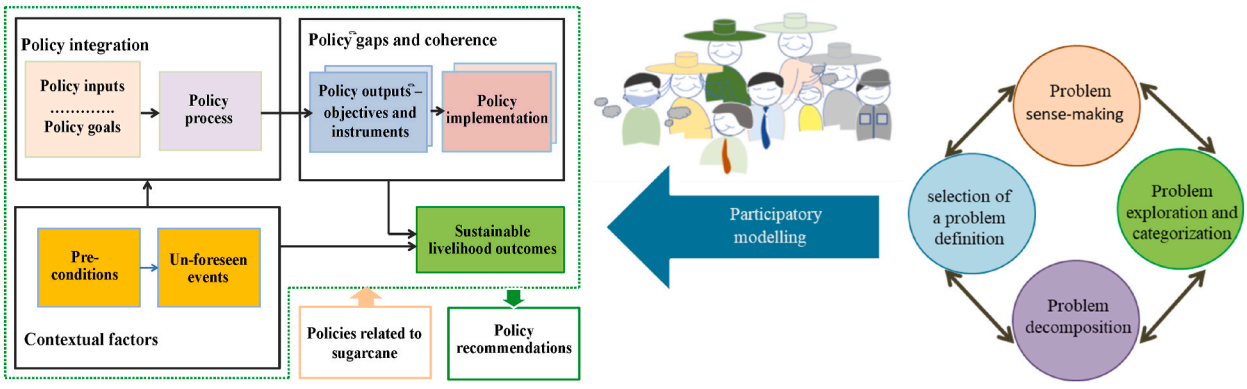

Fig. 1. Research framework of the study: adapted from Chaya et al. [63].

was applied. Chaya et al. [63] combined the coherence analysis framework with the gap analysis. The analysis covered policy formulation, policy gaps and coherence, policy context and policy outcomes and impacts. However, sustainable livelihood outcomes were the focus for policy outcomes and impacts in this study. For policy reframing, the concept of Hoppe [28] was followed but with the participatory modeling method. There are many reports illustrating policy reframing using literature review and field data and being analyzed by researchers [64–66], but a few describing the reframing protocol performed by policymakers, practitioners or stakeholders. Hoppe proposed the method for policy design emphasizing problem structuring. The method is similar to that of van Hulst and Yanow [57]. Problem sense-making (thoroughly understanding the problem through perceptions and experience), problem exploration and categorization (finding causes and effects associated with the problem and placing the problem into a specific category), problem decomposition (determining sub-problems constituting the whole problem) and selection of the problem definition (making claims comprising means-ends of possible solutions) were included. However, participation of stakeholders is not much emphasized and elaborated. As the policy gap and coherence analysis at the level of implementation practice requires a bottom-up approach, engagement of stakeholders is necessary [62]. Participatory modeling was employed for reframing. The research framework for this study is illustrated in Fig. 1. A qualitative approach employing a variety of methods for data collection was conducted.

3.1. Study areas and sampling

The study was conducted in 36 provinces across Thailand where sugarcane is extensively grown and sugar mills are located (Fig. 2). Since there are 47 provinces in total where sugarcane is grown, thus the sampling covers 77 % of the total area. It is estimated that the total number of sugarcane farmers in the country is around 300,000 [67]. However, there is no information about population of sugarcane farmers for each type and region. As the study employed a qualitative approach, the sample size was determined by data saturation [68]. The total number of recruited farmers was reached when there was no new finding (codes or themes) emerging during data analysis. Purposive and snowball sampling methods were performed by recruiting participants from existing networks of farmers and sugar mills. These networks were from learning groups of farmers established by the Office of the Cane and Sugar Board (OCSB) and the Department of Agricultural Extension, Ministry of Agriculture and Cooperatives. There were 268 participants included in the interviews and meetings (Table 1). Among them were farmers, managers/executives of sugar mills, harvesting workers, public officers and representatives of companies selling agrochemicals and farm machines.

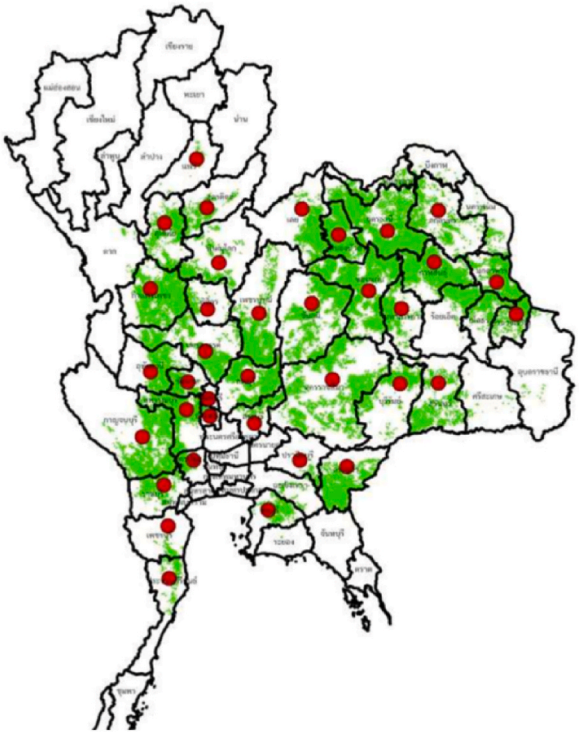

Fig. 2. Cultivation areas of sugarcane in Thailand (green patches) and sampled provinces (red dots). Source: OCSB [67]. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Key participants.

Stakeholders	Participants and distribution[a] (N = North, NE = Northeast, C = Central, E = East)					Method of data collection (face-to-face or phone in-depth interview/focus group discussion)
	Total number	N	NE	C	E	
Farmers						
Medium and large-scale	96	25	32	26	13	Face-to-face (76), phone (14), focus group (1 group, 6 participants)
Small-scale	115	28	35	37	15	Face-to-face (100), phone (15)
Harvesting workers	15	4	5	3	3	Face-to-face and phone
Representatives of sugar mills	25	5	10	9	1	Face-to-face (23), phone (2)
Public officers of the Office of Cane and Sugar Board	5	1	2	2	–	Face-to-face
Officers of the Office of Cane and Sugar Fund	3	–	–	3	–	Face-to-face
Public extension officers (Provincial/District Agricultural Offices)	5	1	1	2	1	Face-to-face
Representatives of distributers of agrochemicals and farm machines	4	1	1	2	–	Face-to-face
Experts (university academics and experienced farmers)	10	1	3	5	1	Face-to-face (9), phone 1

[a] The total number of sugarcane farmers in the country is approximately 300,000. There is no official information about the total number for each type and region.

3.2. Policy analyses

3.2.1. Top-down analysis: qualitative document analysis

The main purpose was to analyze framing of the policy to reduce pre-harvest burning of sugarcane. Qualitative document analysis was performed in five steps, having the criteria for document selection, searching for policy documents, content analysis of policy documents, validation, and finalization [69]. Policy documents were gathered and identified for gaps and incoherence of objectives [62]. For the step of validation, in-depth interviews were conducted with policymakers from the OCSB.

3.2.2. Bottom-up analysis: participatory modeling

3.2.2.1. Elicitation of a shared mental model. A systems approach was applied to capture the whole picture of sugarcane harvesting problems through mental models. A mental model is a cognitive construct that people have in their minds about and in making sense of the world [70]. It is also associated with reasoning and decision making [71]. Personal experience, knowledge, and values were included in the models [72]. Mental models (texts) were elicited from interviewing farmers and sugar mills as key stakeholders. The methodhas advantages of accuracy, completeness, ability in capturing complexity and efficiency in exploring goals-strategies-variables and causal relationships [73].

Participants were encouraged to describe sugarcane harvesting process and related problems. Goals of the harvest, methods to achieve the goals, factors influencing adoption of the methods and values (sustainable livelihood outcomes of farmers) from achieving the goals were investigated. The decision on a particular harvesting method was the effect which the causes led to. There were primarily three harvesting methods; green mechanical (using combine harvesters), green manual and the burnt manual. A face-to-face in-depth interview, phone in-depth interview or focus group discussion was conducted to each individual or group of participants for 45–60 min. Validity was determined by interviewing several key informants in the industry and experts [74].

A shared mental model or qualitative system map was constructed [75]. It is composed of terms (variables) and arrows (associations) to determine causal relationships [76,77]. Working backward allowed connecting variables for causes and effects while redundancy was eliminated [78]. Information obtained from harvesting workers, public extension officers and representatives of companies selling agrochemicals, farm machines and experts was used to supplement and validate the system map. The map was then validated by groups of stakeholders at the meetings.

3.2.2.2. Determination of problem complexity, practical reasoning and perceptions of farmers on the link between sugarcane burning and environmental problems. Criteria of problem complexity include having multiple goals and variables and associations leading to goals, goal conflicts, and uncertainties of information [79]. The scheme structure proposed by Fairclough and Fairclough [48] was followed with some adaptation. It was composed of goals, a means, values, circumstances and cost-benefit. In this study, values are sustainable livelihood outcomes. Argumentation schemes were created using data from the system map. Since the policy of interest addressed environmental problem of $PM_{2.5}$ and climate change from sugarcane burning, relevant perceptions and awareness of farmers were evaluated. Questions related to the issue were asked during the in-depth interviews for elicitation. Frequencies of perceptions were counted and reported without making inference.

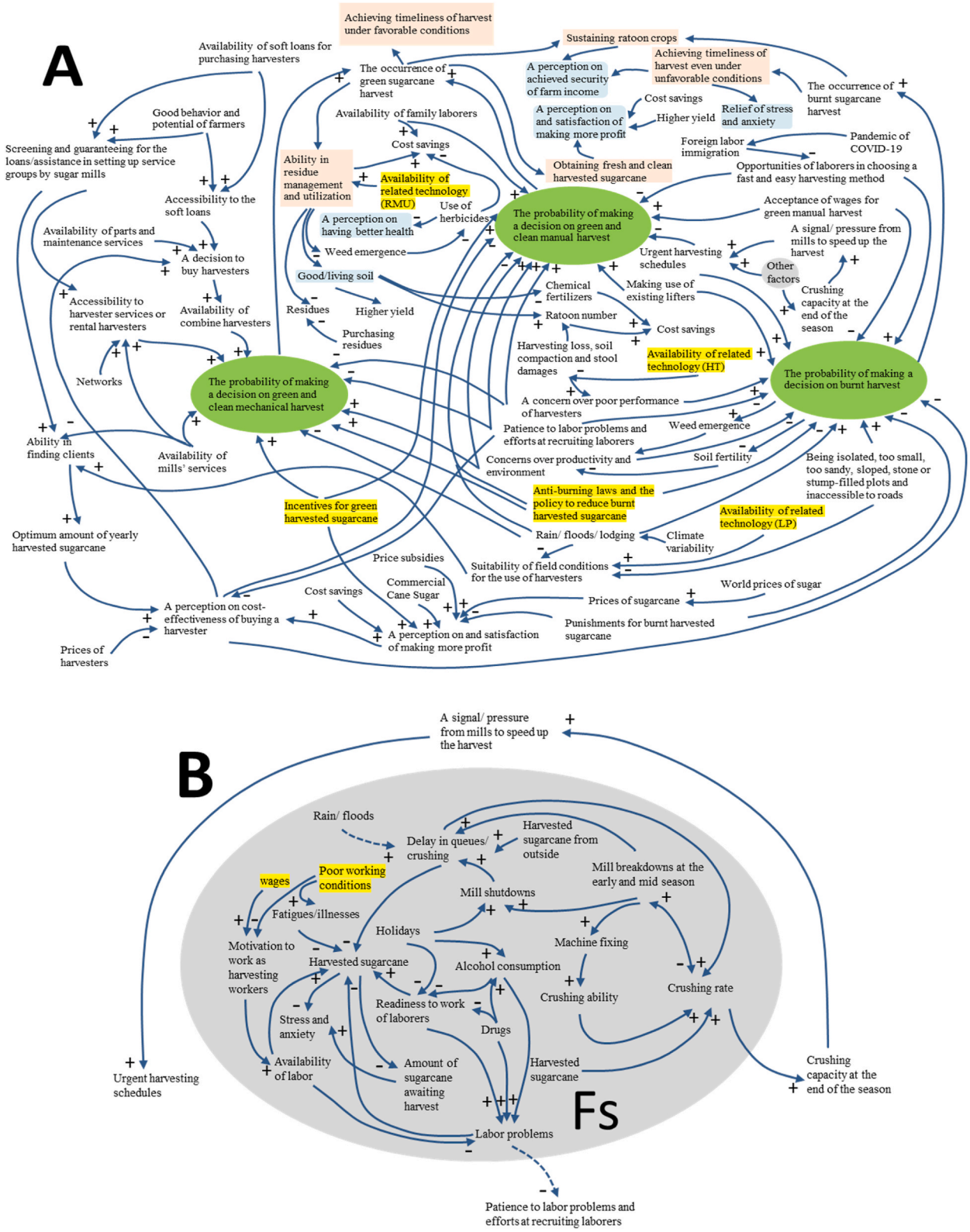

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Fig. 3. The system map elicited from stakeholders, mainly farmers and sugar mills, on the sugarcane harvesting problems (A) with an enlargement of variables and associations within 'Other factors' (B) (+= positive relationship, - = negative relationship; central to the model are the probability of adoption decision on the harvesting methods (green oval); the variables in pink boxes indicate harvesting goals, those in blue boxes indicate prioritized livelihood outcomes and those highlighted in yellow indicate root causes or key drivers; RMU = residue management and utilization, HT = harvesting and transportation, LP = land preparation. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.2.2.3. Validation, problem decomposition and selection of a problem definition. A total of 15 face-to-face group meetings were held in 10 provinces. The number of participants was 6 for each group meeting. Groups comprised 3–5 farmers, 1–2 representatives from sugar mills and 0–2 other stakeholders. All were key informants previously interviewed. At the meetings, the system map and argumentation schemes were validated. Problem decomposition and selection of the problem definition were also conducted by focus groups. To decompose the sugarcane harvesting problems, participants were guided to identify independent pieces of the problem that were important, feasible to be solved, and able to be recomposed [28]. The system map was useful in assisting the groups, capturing the ideas, and indicating key sub-problems. High leverage points were identified. They were the locations of root causes where a major change of the system occurred when applying interventions [80]. For choosing the new problem definition, group participants were guided to consider the most important sub-problems (containing the high leverage points); then, identifying link between that sub-problem with other sub-problems. In general, a problem definition indicates causes and effects of and a guidance of feasible solutions to the problem [81]. The problem definition is equivalent to an argumentation scheme which is derived from exercising practical reasoning. Usually, a policy frame contains a single dominant policy definition [56].

4. Results and discussion

4.1. Sugarcane production in Thailand

In the production year 2021/2022, the total of sugarcane cultivation area in Thailand was 1.38 million hectares [67]. The country produced 92 million metric tonnes of sugarcane and manufactured 10.2 million metric tonnes of sugar [82]. Thailand ranked number two in the world in exporting sugar which was after Brazil but ahead of India, Australia and Mexico [83]. It is estimated that the Thai sugar industry has revenue of 5–6 billion USD a year. There are about 190,000 sugarcane farmers and more than a million employees/workers working in the industry. Sugar contributes 21 % and 48 % of GDP in agricultural sector and food industrial sector, respectively [84]. In addition, production and consumption of ethanol from sugarcane molasses, a by-product also increases the national GDP [85].

4.1.1. The governance of sugarcane and sugar industry

The Thai sugar industry comprises two separate business activities, sugarcane production by farmers and sugar manufacture by millers. Other stakeholders are public authorities, farmer associations, miller associations, export companies, suppliers, a fund and banks [19,86]. Conflicts between farmers and millers may result in a failed cooperation undermining the industry. Thus, the government is required as an intermediary and regulating agent [87]. The Cane and Sugar Act B.E. 2527 is the key policy instrument governing the Thai sugar industry. A law was formulated to primarily solve price conflicts between sugarcane farmers and sugar mills [86]. The Office of the Cane and Sugar Board (OCSB) was a government agency enforcing the law. The Office of the Cane and Sugar Fund (OCSF) was also established to oversee revenue of the industry. The governance requires farmers making a contract with sugar mills. To a great extent, it is similar to the out-grower scheme in Southern Africa [88]. The quota of the amount of harvested sugarcane delivered by each farmer is determined and specified in the contract. Sugar mills must accept all this sugarcane at the prices pre-determined by the intermediary agent.

4.1.2. Key stakeholders

Stakeholders who play a major role in the industry are farmers, millers, and government officers. There are 190,000 farmers, 57 sugar mills, 37 farmer associations and 3 miller associations registered to the OCSB [67]. According to the law, a sugarcane farmer is required to register for membership under a farmer association and then make a contract with a sugar mill. This is to guarantee a market for that sugarcane produced and a certain supply of sugarcane to be crushed. Thus, the demand matches supply.

Farmers are classified by a size of sugarcane cultivation area into small-scale <9.6 ha, medium-scale 9.6–32 ha and large-scale >32 ha [89]. For this study, medium-scale farmers and large-scale farmers are grouped together as medium and large-scale farmers. The number of small-scale sugarcane farmers is estimated at 70 % of the total. There are two types of medium and large-scale farmers; quota heads who provide machinery services, inputs and credits to small-scale client farmers and those who do not [19]. There are two reasons to have client farmers; providing services to gain income including interests and increasing bargaining power. Sugar mills were also able to secure feedstock supply and reduce transaction costs [21].

4.2. The wickedness of sugarcane harvesting problems

4.2.1. Sugarcane harvesting problems prior to the implementation of the policy

Crushing season of sugarcane is about 4–5 months beginning from December and ending around April [16]. However, the right

time for harvesting is during January to February when the sugarcane is ripe and there is a little chance of summer monsoons [21]. Burnt manual was the most popular practice while green mechanical and green manual methods were adopted to a lesser extent. It was estimated that sugarcane was harvested by the burnt manual, green mechanical, and green manual methods at 70%, 25% and 5% respectively. Fig. 3 (A, B) depicts a shared mental model of sugarcane harvesting problems elicited from farmers and sugar mills.

4.2.1.1. Burnt manual harvesting. The burnt manual method is easy and fast. Harvesting workers were still available, though with shortages. Most medium and large-scale farmers had farm machines such as lifters and trucks for harvesting and transport. To invest in combine harvesters might not be cost-effective because of unsuitable fields and insufficient harvesting volume [16]. In addition to higher price of harvesters, most burnt adopters mentioned barriers to the green mechanical method such as being too small and isolated, stone/stump filled and sloped plots [90]. The green manual harvesting was too slow and costly. Thus, the burnt manual method was well accepted by farmers, workers, and sugar mills. However, all burnt adopters knew the adverse effects of burning on sugarcane productivity. Poor soil moisture and fertility, soil compaction, weed emergence, and higher costs for inputs were reported. These impacts were consistent with the report of Carvalho et al. [91]. Moreover, as climate variations were experienced, greater impacts were perceived. The method was considered 'unclean' because impurities from burning could decrease a sugar yield [92].

The government initiated a fine for burnt harvested sugarcane at 0.9 USD/ton of sugarcane starting from the production year 1997/98. The collected fines were given to farmers harvesting green sugarcane as a reward. However, the fine was not effective to reduce burnt harvested sugarcane. Workers preferred the burnt manual method over the green manual method because they were able to harvest a higher amount of sugarcane and obtain higher daily income [93]. Most sugarcane farmers recruited contract workers from the northeast. The contract was on a yearly basis while the pre-paid wage was paid in advance. The money was definitely an interest-free loan; the laborers paid back by working during the upcoming harvest season. Normally, at the end of the harvesting season, workers were likely to obtain a sum of money for a new contract made. The debt cycle continued and lasted if the workers breached the contract and ran away. Alcohol consumption, drugs, quarrels, not paying attention to work were frequently found 'labor problems' (see 'Fs' in Fig. 2). Thailand has encountered labor shortages in agricultural sector in general and during the sugarcane harvesting season in particular [93]. To solve the problem, migrant workers from Cambodia, Laos, and Myanmar were taken up [94]. The outbreaks of Covid-19 prohibited worker immigration which exacerbated a labor shortage [95]. On the other side, labor problems may reflect poor working conditions. Most local harvesting workers reported that the job was unpleasant; they had to work under the sun, in a dust-filled environment and a hot climate [96].

4.2.1.2. Green mechanical harvesting. Large-scale sugarcane farmers whose planting area was 240 ha or above or producing at least 15,000 metric tonnes of sugarcane were likely to own a large combine harvester. However, most providers of the mechanical harvesting service were medium and large-scale farmers producing insufficient amount of sugarcane. Thus, they needed to find client farmers to operate the harvester at its optimal capacity. Thailand began to import combine harvesters in 1991 [97]. At the moment, it is estimated that there are 1800–2000 large combine harvesters used in the country. Most of them are used harvesters imported from Australia, Brazil, and USA. The government had initiated an assistance program since 2010 providing farmers soft loans to purchase harvesters. Potential farmers were required to assess cost-effectiveness and ability in repayment. Sugar mills assisted these farmers in seeking clients. The price of an imported new machine was around 12 million Baht (345,000 USD) whereas that of a used one was about half that. Sugar mills were assigned by the authorities to guarantee the loans requested by individual farmers. Therefore, farmers receiving the loans were those having a good record of paying off debt, sufficient collateral, and good behavior and cooperation with the mills.

Combine harvesters demand suitable field conditions. Growing sugarcane for the mechanical harvesting needs a row spacing at least 1.5 m [98]. However, a narrower row spacing was practiced by most small-scale farmers. They had fields that were too small, scattered, sloped, and stone or stump-filled, or inaccessible to roads. Other constraints were poor yield of ratoon crops, lodging, sandy soil texture, arson and flame spread, availability of parts and maintenance services and rainfall. Monsoons and heavy rainfall interrupted the use of these heavy machines and delayed the harvest. Heavy harvesters and trucks caused soil compaction and poor growth of sugarcane. Harvesting losses were observed as lodged sugarcane hindered feeding. Damages to sugarcane stools were induced by feeding force of the machine. Carelessness during unloading resulted in the sugarcane billets falling on the ground contributing those losses.

Green harvesting generates 10–20 t/ha of leaves and tops regarded as harvesting residues or trash [99]. Trash derived from the green mechanical method was beneficial to farmers utilizing them as soil cover to prevent a decrease in soil moisture and weed emergence. In addition, trash was decomposed to provide organic matter and nutrients. This practice improved physical and chemical properties of soil and enhanced diversity of soil microorganisms and arthropods [100,101]. The latter are good for biological control of sugarcane pests. Thus, farmers were able to decrease the use of agrochemicals such as fertilizers, herbicides and pesticides. Decomposition of sugarcane trash provides carbon and nutrients required for growth of plant roots and soil microorganisms [102]. In this study, a majority of farmers (95%) practiced trash blanketing and trash incorporation. Since residues are a good fuel, a considerable number of sugar mills purchased them to produce electricity. However, most interviewed farmers perceived it was much cost-effective to keep and utilize all residues rather than selling them. It must be noted that a 100% retention of trash may be too much for blanketing [103]. Some farmers used biofertilizers containing fermented manure and urea to speed up decomposition of trash. Adding a culture of cellulolytic bacteria may increase decomposition efficiency [104]. Thus, research exploring optimal amount of trash for blanketing and decomposition in the Thai context should be conducted.

4.2.1.3. Green manual harvesting. Green manual harvesting had been primarily practiced since the beginning of the Thai sugar industry. Later, it was replaced by the burnt manual method as sugarcane productivity and labor shortages increased. Farmers adopting the green manual method prior to the policy implementation were primarily small-scale farmers growing 3.2 ha of sugarcane. Most small-scale farmers adopting the green manual method were in the northeastern region. Relying on family labor allowed to save costs for the harvest and transport [19]. Small-scale production allowed them to achieve timeliness of harvest though by the green manual method. Nevertheless, those growing over than 3.2 ha might require hiring harvesting workers. Problems related to labor were similar to burnt harvesting. All interviewed farmers adopting the green manual method appreciated the benefits of residues. They experienced moderate and severe droughts during the past decade. Residue management was among the key adaptive strategies.

For all three methods of harvesting, there were also problems affecting timeliness of harvest. Key obstacles were inefficient queuing, breakdowns of crushing machines and mill shutdowns. Since most sugar mills increased their crushing capacity during the past 10 years, the demand for feedstock increased as well. Milling overloads resulted in the breakdown of machines. It was reported by farmers that there were shutdowns 2–3 times per year (3–5 days for each) for most sugar mills which affected harvesting schedules, queuing, and timeliness of harvest.

4.2.2. Framing sugarcane harvesting problems

Practical reasoning of farmers adopting sugarcane harvesting methods is shown in Fig. 4. Different claims were made for green and burnt practices. Achieving timeliness of harvest was the top priority goal. Green mechanical and the burnt manual methods were perceived much more to meet timeliness than the green manual method. However, farmers adopting the green mechanical or green manual preferred benefits such as incentives and the use of residues. Additional goals were obtaining fresh and clean harvested sugarcane, sustaining ratoon crops, and ability in residue management and utilization. Relevant livelihood outcomes obtained from achieving the goals were 'relief stress and anxiety from harvesting problems', 'a perception on security of farm income', 'a perception and satisfaction of making more profit', 'a perception on having better health' and 'good/living soil'. These livelihood outcomes were consistent with those reported by Chaya and Gheewala [23].

4.2.3. The policy to reduce burnt harvested sugarcane

Smog blankets happening in Bangkok during 2018–2019 were found to be associated with biomass burning and adverse

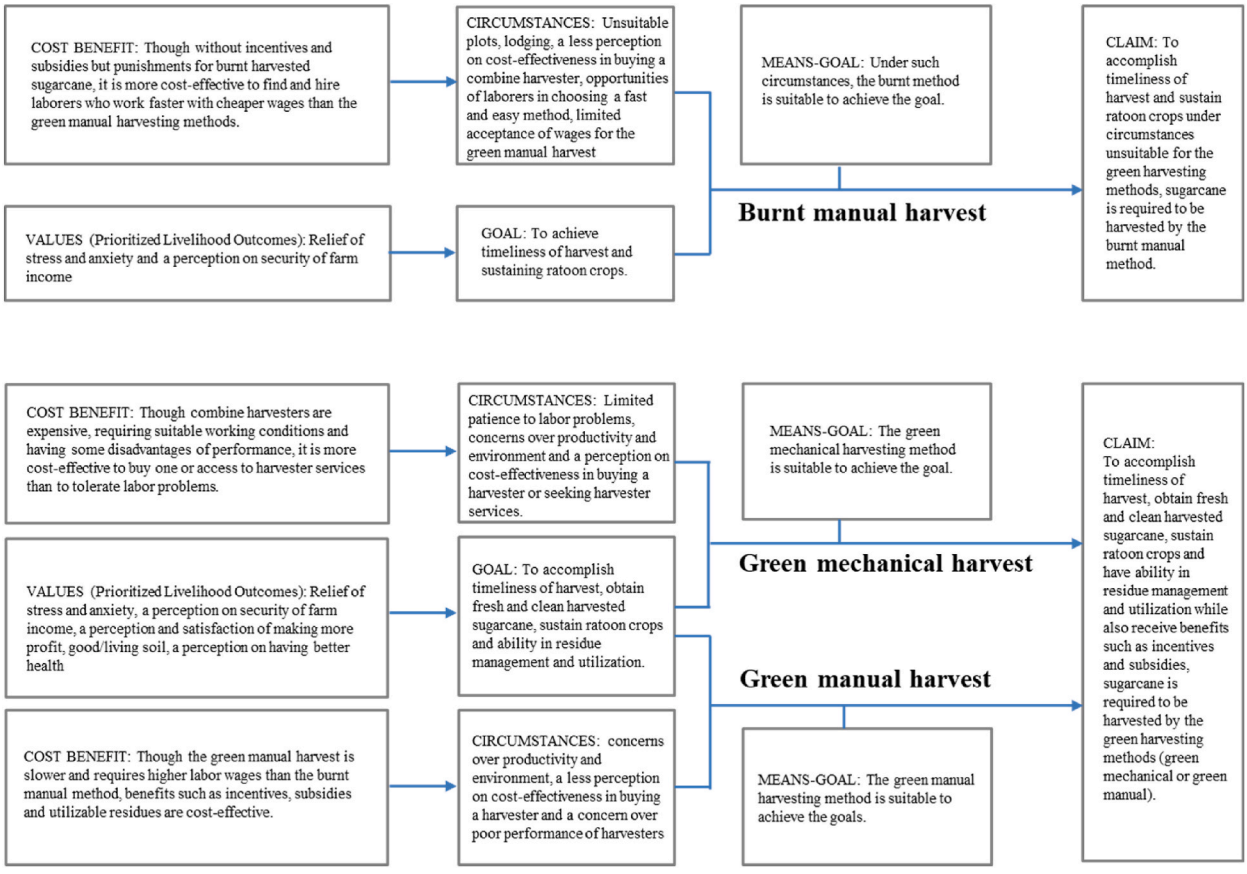

Fig. 4. Framing the sugarcane harvesting problem by farmers prior to the implementation of the policy to reduce burnt harvested sugarcane.

meteorological conditions [105]. It was scientifically revealed that fine particulates ($PM_{2.5}$) a product of burning, primarily contributed this environmental problem [18]. The government responded to public concerns by putting air pollution problems on the national agenda in 2019. The OSCB initiated the policy to reduce burnt harvested sugarcane.

According to the policy, its main goal was to reduce burnt harvested sugarcane within three consecutive years. Harvested sugarcane was projected to decrease from 60-70%–20%, 10% and 0–5% in each consecutive year (measure 1). Sugar mills were asked to: not accept burnt harvested sugarcane from farmers over the pre-determined amount; and adopt the price assurance program for green harvested sugarcane for two consecutive years (measure 2). Thailand has enforced related laws such as the criminal law, the Public Health Act, B.E. 2535, and the Forest Act, B.E. 2484. Penalties include imprisonment and fines. It has been observed that enforcement of these laws by public authorities are ineffective as burning is persistent [106]. Provincial governors were assigned by the government to oversee burning problem. Soft loans were provided for purchasing combine or whole stalk sugarcane harvesters and other machinery (measure 3). The OCSB lent machines for leaf removal to certain farmer groups (measure 4). The Ministry of Industry also cooperated with a cement company located in the central region of the country to buy harvesting residues for electricity production (measure 5). Subsidies for green harvested sugarcane were provided to farmers (measure 6). The way policymakers framing the harvesting problem of sugarcane is illustrated in Fig. 5.

All those measures were absolutely nothing new. Enforcement and subsidies are often used by the OCSB in particular and by many public authorities in general. Government policies providing subsidies, incentives and price guarantees draw large attention from farmers [107]. Agricultural subsidies are shown to generate a cycle of fault demand and excess supplies of agricultural products which hinders structural transformation [108]. It was clear that reduction in $PM_{2.5}$ emissions generated by the burnt harvest was a primary concern.

4.2.4. *Sugarcane harvesting problems after the implementation of the policy*

During 2009–2019, burnt harvested sugarcane contributed 64% of the total output. After the policy implementation (Fig. 6), it decreased to 50%, 26% and 27% in the first, second and third year, respectively [82]. It was unsuccessful to reduce to 10% or less by the second year. The failure led the OSCB revising the policy to extend the time frame by three more years.

The policy benefited farmers who already adopted the green methods. The green incentive was regarded as a bonus. However, farmers adopting the burnt method were affected. Harvesting wage for the green method was higher. The farmers did not perceive that the green subsidy was sufficient. The policy induced a new method of harvest in 2021, green but unclean by frustrated farmers. The method was as easy and fast as the burnt one. The harvested product was regarded as unclean (containing impurities above 7%). Without good practices, impurities from trash and soil in general can account for 10–20% of harvested sugarcane [109]. Financial penalties for this harvested sugarcane was at 0.6 USD/ton of sugarcane. Farmer dissatisfaction came from two reasons. First, they saw the policy unnecessarily increasing a harvesting cost. The burnt method had been performed for almost 40 years. But, smog blankets were a recent problem. There were many sources of $PM_{2.5}$, but the government chose to penalize only sugarcane farmers. Farmers were also suspicious since the government did not report how the levels of $PM_{2.5}$ was decreased by the policy. Second, residues were utilized by most sugar mills for electricity production, thus sugar mills were responsible to find a method to separate trash from sugarcane.

4.2.5. *Perceptions of farmers on environmental problems*

$PM_{2.5}$ emissions through sugarcane burning concerned public and policymakers [17]. Though, the policy to reduce burnt harvested sugarcane does not address climate change, the issue is included in the National Economic and Social Development Plan and the 20-year National Strategy [63]. Moreover, in line with the Paris Agreement, the country has a pledge to reach carbon neutrality by 2050 and net zero by 2065 [110]. Therefore, farmer perceptions on global warming/climate change were also investigated.

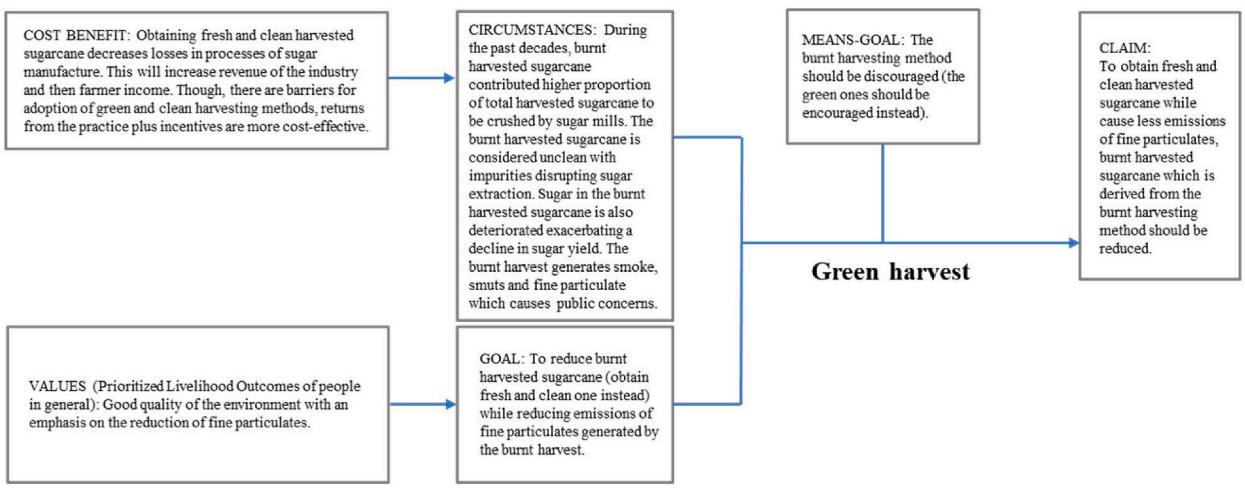

Fig. 5. Framing sugarcane harvesting problems by policymakers.

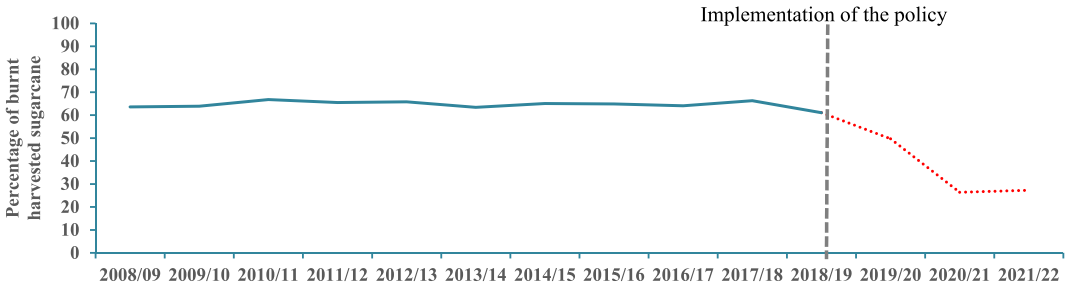

Fig. 6. Percentage of burnt harvested sugarcane during the production year 2008/2009 to 2021/2022. Source: OCSB [82].

Most farmers perceived that the burnt method caused environmental problems while a lesser percentage of them disagreed or were uncertain (Fig. 7A). When asked those who agreed, a large number of farmers raised the problems that were visible such as smoke, dust, 'black snow' and damage to life and property. Invisible problems such as emissions of $PM_{2.5}$ and global warming/climate change were little recognized (Fig. 7B). This was consistent with the study of Rahman [111].

Nevertheless, it was obvious that the problems related to climate variability were highly concerned (Fig. 8). Farmers were aware of repeated cycles of heavy rainfall followed by a long dry spell, severe droughts, hot environments and flash floods. Those adopting the green methods and utilizing harvesting residues were shown to adapt to climate change impacts. Rice was another crop that climate change adaptation was extensively evident [112]. However, sugarcane farmers were unable to associate sugarcane burning with climate change/global warming. Understanding its scientific mechanism may raise awareness of the causes and impacts [113].

4.2.6. Characteristics of the wickedness of the sugarcane harvesting problems

According to Schaffernicht [77], complexity of the problems was indicated by large numbers of variables (65) and associations (102). Uncertainties of information were determined including the number of harvesters, suitable land areas, the number of laborers required, the number of farmers harvesting green or burnt and the number of potential farmers providing the harvester service. Another crucial uncertainty was a lack of knowledge and understanding about related environmental problems. A goal conflict between 'timeliness of harvest' and 'obtaining fresh and clean harvested sugarcane' was perceived by farmers adopting the burnt method. As sustainable livelihood outcomes were attached to goals, a goal conflict also resulted in a value conflict. This was similar to studies of Biggs et al. [114] and Moon et al. [115] that show the association between value conflicts and policy failure. Values are very important in judging things whether they are good or bad and moral merit in taking actions in a given circumstance [52]. There were also goal-independent values such as 'a concern over poor performance of harvesters', 'concerns over productivity and environment', and 'a perception on cost-effectiveness of purchasing a harvester'. Interconnections among facts and values primarily contributed to the wickedness of the problem [26]. A summary of the wickedness characteristics of the sugarcane harvesting problems is provided in Table 2.

4.3. Relevance of the wicked problems and policy ineffectiveness

There were two key problems in relation to framing, 1) incomplete problem sense-making and 2) weak problem definition and undesired problem choice. The problem definition identified from the policy content reflected incomplete understanding policymakers to the harvesting problems. Providing soft loans for investment in farm machines was key. However, there were barriers to access and use of mechanization particularly combine harvesters. Most farmers adopting manual harvests did not have 'a perception on cost-effectiveness of buying a harvester'. This was primarily a result of not having 'suitability of field conditions for the use of harvesters'. Incomplete sense-making by policymakers was derived from gaps of knowledge and values from multiple stakeholders [116].

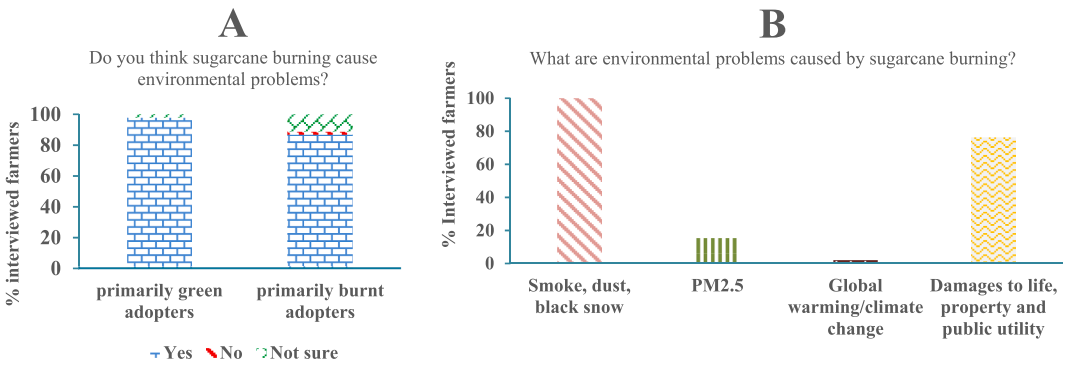

Fig. 7. Percentages of sugarcane farmers: believing in environmental problems from sugarcane burning (A) and identifying such problems (B).

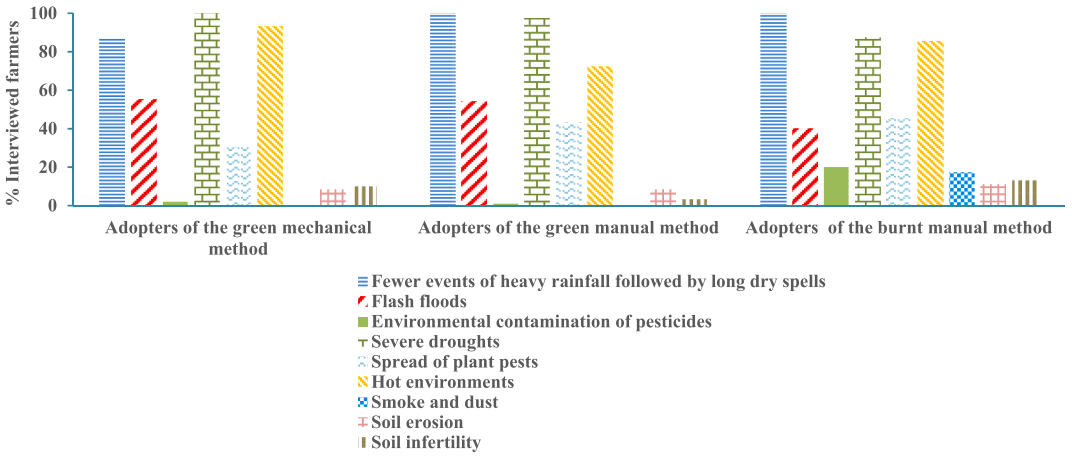

Fig. 8. Percentage of sugarcane farmers having awareness on important environmental problems affecting their livelihoods.

Table 2
Wickedness characteristics of the sugarcane harvesting problems.

Parameters indicating wickedness	Harvesting methods		
	Green mechanical	Green manual	Burnt manual
Complexity of facts			
•Number of perceived important variables (excluding goals and prioritized livelihood outcomes)	53	39	34
•Number of associations	68	51	48
•Uncertainties of information	•Number of existing workable harvesters •Percentages of green mechanical and green manual harvested sugarcane	•Number of local and foreign laborers required for the harvest •Total cultivation area able to be combined into larger plots, leveled and made suitable for the use of combined harvesters •Number of farmers having a potential to be a harvester service provider	•Amount of burnt harvested sugarcane •Information related to farmers and their constraints to the green harvest
	•Knowledge and understanding on environmental problems and impacts related to sugarcane burning		
Multiple goals and sustainable livelihood outcomes			
•Primary goal	•Timeliness of harvest	•Timeliness of harvest	•Timeliness of harvest
•Secondary goals	•Obtaining fresh and clean harvested sugarcane •Sustaining ratoon crops •Ability in residue management and utilization	•Obtaining fresh and clean harvested sugarcane •Sustaining ratoon crops •Ability in residue management and utilization	•Sustaining ratoon crops
•Perceived goal conflict(s)	Timeliness of harvest vs. Obtaining fresh and clean harvested sugarcane		
•Primary sustainable livelihood outcomes	•Relief of stress and anxiety from harvesting problems •A perception on achieved security of farm income	•Relief of stress and anxiety from harvesting problems •A perception on achieved security of farm income	•Relief of stress and anxiety from harvesting problems •A perception on achieved security of farm income
•Secondary sustainable livelihood outcomes	•A perception and satisfaction of making more profit •Good/living soil •A perception on having better health	•A perception and satisfaction of making more profit •Good/living soil •A perception on having better health	–
Interaction of complexity of facts and values:			
•Variables related to the probabilities of choosing the harvesting methods and goals were shown to link to the goal-dependent values (prioritized livelihood outcomes). •There were also goal-independent values connecting to the variables of facts such as 'a perception on cost-effectiveness of buying a harvester', 'a perception on and satisfaction of making more profit'			
An attempt to solve to the problems leads to a new problem:			
• The green but unclean harvest was adopted.			

Ignoring their perspectives or applying wrong assumptions of what they view may adversely affect policy effectiveness [117]. A majority of the committee members formulating the policy were public officers, large-scale sugarcane farmers and university academics. There was no representative of small-scale farmers or group farmers and those relying on the burnt method. Engagement of multiple stakeholders may be useful in determining differences and similarities where gaps exist and effective improving mutual understanding and negotiating solutions to the problems [68,118,119]. Joint knowledge co-produced by stakeholders are required during the process of problem sense-making [120]. Production of joint knowledge may occur in networks where several forms of knowledge interact, are transformed and lead to solutions [121]. Though, it may be impossible to completely solve the wicked problem, mutual understanding and collective actions to improve the problem situation should be emphasized [116].

The strength of the frames, weak or strong, affects public beliefs [122]. A weak policy frame which has less persuasiveness may be constructed from an incomplete problem definition [56]. In the case of sugarcane harvesting problems, selecting $PM_{2.5}$ to be framed did not convince most farmers. They were shown to construct and prioritize a number of competitive frames which were ignored by policymakers. This indicated conflict framing and deep disagreement [123]. Moreover, extreme disagreement may engender a conspiracy theory [124]. As farmers harvesting green but unclean had strong disagreement with the policy, they thought that policymakers made a groundless story to force them to adopt the green methods. Nevertheless, the problem choice benefited general citizens affected by air pollution, large-scale farmers requiring loans to invest in farm machines and machinery distributers. Having a close relationship with policymakers made organized large-scale farmers and sugar millers accessible to advisory bodies in policy consultation. Therefore, interest groups tend to advocate economic policy issues favoring them [125]. As framing involves the coherence of problem definition and proposed solutions, a weak problem definition and an undesired choice of problem definition inevitably contribute to policy failure [56].

4.4. Reframing the sugarcane harvesting problems

In general, for the case of policy failure, it is a priority to review if insufficient problem understanding, inadequate knowledge and goal conflicts are present [27]. Therefore, inappropriate framing should be corrected by reframing. Specific to the case of wicked problems, reframing is also a prioritized recommendation [126,127]. Reframing steps of sense-making, exploration and categorization of the sugarcane harvesting problems are illustrated in previous subheadings. The rest are decomposition and selection of a problem definition.

4.4.1. Decomposition of the sugarcane harvesting problems

From the system map, critical root causes such as inefficient green technologies (RMU, HT and LP) and labor availability were identified (Fig. 3). In addition, there were two key drivers to the green harvesting method; financial incentives/subsidies and laws/policy. These root causes and drivers are the high leverage points where the right interventions are applied and substantial change is expected to occur. As the high leverage point focuses on desirable goals and values of sugarcane harvesting, paradigm changes to sustainable sugarcane harvesting (and also production) is required. This is in line with Abson et al. [128]. Group participants proposed 3 sub-problems, 1), 3) and 4). The subproblem 2) was suggested by experts.

1) Inefficient green harvesting method

It is agreed by all groups of stakeholders that inefficiency of the green harvesting methods is key. There is a lack of appropriate technology for the green harvesting method. The technology is required to overcome constraints of the green method for different production scales [129]. In addition, the technology should be available, accessible and affordable for small-scale farmers [130].

2) Conflicting alignment of values among those of farmers and policymakers.

Farmers prioritize the goal ‘timeliness of harvest’, then the attached value ‘the relief of stress and anxiety from harvesting problems’. Under the current circumstances, the burnt manual method effectively fulfils the prioritized goal and value while the green methods do not. The OCSB should educate farmers about environmental problems and livelihood impacts associated with sugarcane harvesting methods. Positive livelihood outcomes were achieved by group sugarcane farmers adopting green harvesting and trash use [23]. These values align well to those of policymakers. Incentives may also be used to assist value alignment [26].

3) Unsustainable workforce

Sugarcane farming relies upon intensive workforce especially during the harvesting. Labor problems including a shortage of laborers may reflect unpleasant working conditions, unfair wages and poor welfare [95,96]. As research and development in the green technology takes time, labor is still required during the transition. Nevertheless, full mechanization does not mean no requirement of laborers. Thus, sustainability related to labor is of concern.

4) Ineffective institutional instruments

Subsidies, incentives, and punishment are drivers for adoption of green harvesting [13]. However, these tools are not evenly available. The legal enforcement to discourage sugarcane burning is ineffective in many areas. Gaps and inconsistent implementation

practices may contribute to the problem. Uncertainty of information should be reduced by gathering sufficient information, prioritizing its relevance and adapting to new knowledge [79]. Finally, policy communication by the OCSB should be efficient.

4.4.2. New problem definition of the sugarcane harvesting problems

The new problem definition is focused on the promotion on adoption of efficient green harvesting. A constructed claim through reframing is illustrated in Fig. 9. There are four goals to pursue; 'timeliness of harvest', 'obtaining fresh and clean harvested sugarcane', 'sustaining ratoon crops' and 'utilize harvesting residues to improve sugarcane productivity'. To achieve the goals, the efficient green method is to performed. The new problem definition is shown to address the sugarcane harvesting problem by the following reasons. The complexity of the sugarcane harvesting problem is unfolded. Relevant and important variables influencing the adoption decisions on the harvesting methods are known. In addition, uncertainties from gaps and incoherence of knowledge and values are determined. Thus, appropriate technologies that overcome barriers to green harvesting may be redesigned and fabricated to the requirements of the users. The key is to allow the users to perceive their opportunities for accessibility and use [131].

The efficient green harvest is perceived to carry values compatible to those of policymakers and farmers. Thailand has a commitment in achieving the sustainable development goals following to the 2030 Agenda for Sustainable Development [132]. Green sugarcane harvesting will contribute to the achievement of targets 2.3 (to double increase agricultural productivity and income of small-scale farmers) and 2.4 (to ensure sustainable food production systems and adopt resilient agricultural practices). In addition, the green harvesting practice also supports the BCG Model initiated by the Thai government, in the area of agriculture and food [133]. Adoption of sustainable practices and technologies is one among the policy goals that green sugarcane harvesting addresses. Though most sugarcane farmers perceived little about impacts of burning on global warming/climate change and even $PM_{2.5}$, policymakers should educate farmers on the association between burning and such impacts. Relevant scientific knowledge should be made simple to understand and communicated well. The key is to link livelihood advantages to green harvesting.

4.4.3. A comparison of policy framing by policymakers and policy reframing by participatory modeling

It is clear that the participatory modeling is robust in obtaining the new policy frame. Qualitative and simple models encourage participants to brainstorm and explore solutions to the problems [134,135]. Utility of models for decision making may require a balance between sophistication and representativeness [136]. The model in this study is simplistic, but at the same time sufficiently representing reality. A lack of participation of stakeholders in the previous framing is the key gap. Key to the process of reframing is to structure the problem through a particular order of conception, planning and action [137]. However, this study suggests proposing policy actors as another component in structuring policy frames [57]. Structuring the method of reframing enhances performance of participants in understanding and finding solutions to a complex problem [138]. While Hoppe [28] principally provides a conception of reframing, this study illustrates an empirical case study extending and highlighting methods of engagement, engaging actors and expected outputs that allow the process being easy to follow. Gaps and coherence of previous framing were also able to be determined. A summary of methodology comparison is provided in Table 3.

4.4.4. Study limitations

Though a participatory modeling technique is proved to be robust and useful in policy reframing, it is only a tool in a set of toolkits for participation research. Further studies should employ multiple tools or compare results obtained from different tools for policy reframing. A quantitative approach may be appropriately used in problem exploration and categorization to ensure generalizability. Developing a quantitative technique in finding high leverage points should be encouraged (e.g., ranking, simulation). Other stakeholders such as consumers of sugar and biofuels and people affected from sugarcane burning should be included in the modeling.

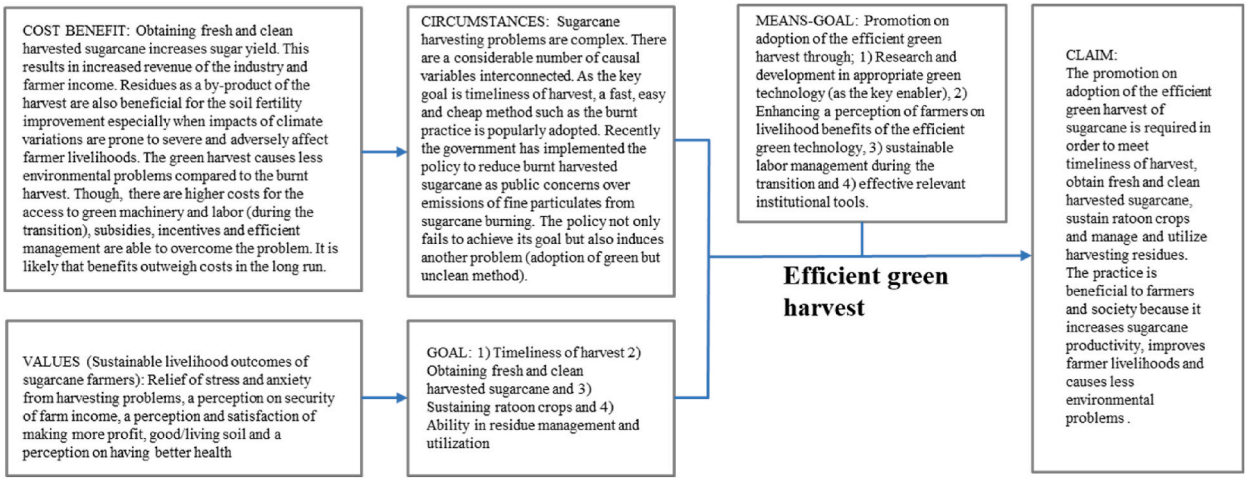

Fig. 9. Reframing the sugarcane harvesting problems.

Table 3
A comparison of previous framing and reframing through participatory modeling.

Process		Previous framing	Gap and/or coherence of previous framing	Reframing
Problem sensing	Emerged problem(s)	Burning sugarcane fields is believed to cause emissions of fine particulates	–	Ineffectiveness of policy to reduce burnt harvested sugarcane/Adoption of green but unclean harvesting method
	Being perceived by	Public		The Office of the Cane and Sugar Board/sugar millers
	Being emerged from	Government's response to public		External evaluation bodies (through research)
	Being sensed by	The Office of the Cane and Sugar Board		Stakeholders
	Sources of information/data for sensing	Official data collected by the Office of the Cane and Sugar Board	A lack of validated data/incomplete information/	Narratives of stakeholders/Official data collected by the Office of the Cane and Sugar Board
	Method(s) of sensing	Expert consultation and deliberation	Not retrieving complete information/preferences of experts	Elicitation of individual and group mental models (through individual in-depth interviews or focus groups)
	Involving key policy actors	Ad hoc advisory committee for the Office of the Cane and Sugar Board	A lack of participation of stakeholders from various groups	Stakeholders
	Output	A problem description and a problem frame	Incomplete problem sense-making	Individual and group mental models/a shared mental model (system map) and frames
Problem exploration and categorization	Method(s) of exploration and categorization	Expert consultation and deliberation	Lack of participation of stakeholders from various groups	Focus groups
	Involving policy actors	Ad hoc advisory committee for the Office of the Cane and Sugar Board		Stakeholders
	Output	A thoroughly discussed frame and a solution plan	A weak frame	A validated system map and a new proposed frame
Problem decomposition	Method(s) of decomposition	Expert consultation and deliberation	Lack of participation of stakeholders from various groups	Focus groups
	Involving policy actors	Ad hoc advisory committee for the OCSB/the OCSF/a cement company/Ministry of Interior (provincial governors)		Multiple stakeholders
	Output (solvable sub-problems)	• Insufficient combine harvesters •problems related to management of harvesting residues •A lack of motivation of workers to the green harvesting method •acceptance of burnt harvested sugarcane by sugar mills	Sub-problems are too specific and not representing problems primarily encountered and sensed by stakeholders	•Inefficient green harvest (key leverage point) •Conflicted alignment of values of those stakeholders and policymakers •Unsustainable workforce •Ineffective institutional instruments
Selection of a problem definition	Method(s) of selection	Expert consultation and deliberation	A lack of participation from multiple stakeholders	Focus groups
	Involving policy actors	The Office of the Cane and Sugar Board		Multiple stakeholders
	Output	The problem of sugarcane burning which is linked to the environmental problem of $PM_{2.5}$ (the argumentation scheme depicted in Fig. 5)	Weak problem definition as the problem of $PM_{2.5}$ is not convincing while the key problem sensed by most stakeholders (timeliness of harvest) is not well defined.	The problem of inefficient green harvest which is linked to sugarcane productivity and farmer livelihoods. (the argumentation scheme illustrated in Fig. 9)

4.4.5. Policy implications

Reframing the policy to reduce burnt-harvested sugarcane is suggested. Policymakers should follow steps recommended by this study. Key is to encourage participation and include multiple types of farmers especially those of small-scale and adopting pre-harvest burning of sugarcane. For the case of persistent sugarcane burning, the proposed new frame and problem definition obtained from this research is ready for policy amendment. The Office of the Cane and Sugar Board (OCSB) is the public agency overseeing this policy. This research results and policy recommendations have been submitted to the agency already. Measures associated with efficient green harvesting methods, alignment of values for green harvesting, sustainable workforce and efficient institutional instruments maybe properly designed and delivered by the agency. Though only the case study of Thailand was illustrated by this research, the method is powerful and useful for global application especially in the sugarcane producing countries where the pre-harvest burning problem is intractable. For other policy problems related to sugarcane production, agricultural systems or wicked problems, the method of framing/reframing elaborated by this study is applicable in a variety of contexts.

5. Conclusions

The study aimed at answering the question of why sugarcane burning was persistent (though with anti-burning laws and policy to reduce burnt harvested sugarcane). Sugarcane burning was only an aspect of the sugarcane harvesting problems which were regarded as wicked. Harvesting methods were central to the harvesting problem. A shared mental model elicited from sugarcane farmers and sugar mills revealed drivers and barriers to the three harvesting methods. These variables were facts, values and a combination of indivisible facts and values contributing the wickedness.

Farmers adopting different harvesting methods selected different harvesting problems to be framed. All frames were associated with technical advantages/disadvantages leading to different goals and values achieved. However, policymakers instead chose to frame the problem of $PM_{2.5}$ from sugarcane burning. It was obvious that sustainable livelihood outcomes played an important role in value-based practical reasoning or argumentation for framing sugarcane harvesting problems. This study first addressed the role of sustainable livelihood outcomes as policy impacts in policy coherence analysis. As the burnt manual method is efficient (easy, fast and inexpensive), it is popular and persistent. Framing a policy problem against the burnt method is challenging.

The policy to reduce burnt-harvested sugarcane was ineffective in achieving its goals. Burnt harvested sugarcane was not reduced as expected. There was poor framing resulting from incomplete problem sense-making due to the exclusion of information and opinion from all stakeholders, especially small-scale farmers. Moreover, a weak problem definition from undesired problem choice was indicated. A majority of farmers including those adopting green harvesting had doubts on the association between sugarcane burning and environmental problems of $PM_{2.5}$. Moreover, farmers were more aware of visible environmental impacts than invisible environmental impacts such as $PM_{2.5}$ and global warming/climate change. Nevertheless, impacts of climate variability on livelihoods were encountered and perceived by a majority of farmers. Policymakers should educate farmers scientific knowledge linking burning and other farming activities with environmental problems especially climate change. As Thailand has a commitment in achieving the goals of carbon neutrality and net-zero greenhouse gas emissions, the issue is a top priority.

Since framing sugarcane problems was a key problem, reframing was required. Through problem decomposition, inefficiency of the green harvesting methods linked to sugarcane productivity and farmer livelihoods was key. It was selected to be defined, highlighted, and considered as a guidepost for better solutions. Efficient green harvesting is expected to perform superior to the existing green methods and the burnt harvesting method. To encourage adoption of the practice, alignment of sustainable livelihood outcomes should be promoted and effective institutions should be employed. During the transition, as harvesting workers are still required, sustainable workforce management should be addressed.

To better understand and propose effective solutions to a wicked problem, one may require an application of a variety of concepts, a systems approach and engagement of relevant stakeholders. This empirical study demonstrates a response to such purposes. It contributes originality to the science of policy analysis dealing with framing/reframing policy problems in general and that to wicked problems in particular.

Ethic statement

This study was reviewed and approved by the Mahidol University Central Institutional Review Board (MU-CIRB), with the approval number: MU-CIRB 2020/099.2804. All participants/patients (or their proxies/legal guardians) provided verbal informed consent to participate in the study. Since the research project and all participants required anonymity, obtaining written informed consent was not possible. However, to conform to the ethical standard, all participants were informed about the research project, ethical standard and requirement of verbal informed consent.

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Data availability statement

Data associated with this study cannot be deposited into a publicly available repository because of confidentiality.

Additional information

No additional information is available.

CRediT authorship contribution statement

Wirawat Chaya: Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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