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StrawFeed model: An integrated model of straw feedstock supply chain for bioenergy in China

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ABSTRACT

With the growing concerns of fossil fuel scarcity and its negative impacts on global environment, bioenergy as an alternative energy source has attracted more attention as climate change mitigation. As one of the largest carbon emission and agricultural production countries in the world, China has abundant straw resources and great potential for energy utilization, and the number of straw-to-energy business projects is increasing dramatically. Correspondingly, there is a strong demand to design a stable and sustainable straw feedstock supply chain. However, due to the uncertainty of system boundary and neglect of potential risks, the procurement cost for bioenergy conversion plants (BCP) is varied significantly. Model is a critical approach in strengthening the understanding that leads to promoting supply efficiency. Therefore, an open-source & GIS-enabled linear programming model, named StrawFeed, is proposed to simulate the operation of straw feedstock supply. The costs of raking, baling, loading and transporting have been investigated as components in the StrawFeed model. The model is applied to case analysis of corn straw supply in Nongan county, a major corn production region in Northeast China. The results illustrate that the straw supply cost could be 172 CNY/ton, and the reasonable profit allocation mechanism could achieve the triple-win solution among farmers, brokers, and BCP. Furthermore, the challenges and opportunities for optimization are investigated with scenario analysis, based on unique circumstances and supporting policies in China. Unfavorable weather could delay the available working day, and thereby cost would increase up to 13%. The optimized scheme of straw utilization could achieve better environmental and ecological benefits, but the transportation distance for straw supply has to be expanded and the increased cost would be up to 53%. Cross-regional operation of agricultural machinery and machine procurement subsidies could reduce the cost by 18% and 5% respectively. This model is helpful to estimate accurate supply cost and deploy sustainable straw feedstock supply, which could contribute to assisting investors and policymakers for bioenergy industry in China.

1. Introduction

The greenhouse gas emissions during fossil fuels consumption accelerate the progress of global warming and thereby resulting in induced climate change hazards. In recent years, using renewable clean energy to substitute conventional fossil fuels and help mitigate climate change has gradually become a popular topic in public. Also, the scarcity of fossil fuels brings about the worry of national energy security. If the supply is terminated by the unforeseeable risks, the operation of social system would be at a standstill. China has been the largest carbon emission contributor in the world according to the latest estimation released from global carbon budget 2020 (Friedlingstein et al., 2020). Based on the dual concerns from emission mitigation and national energy security, bioenergy could be regarded as a valuable alternative to fossil fuels, and it has also been encouraged by Chinese government with incentive policy.

The term biomass, in general, refers to renewable organic matter generated by plants through photosynthesis (Cundiff et al., 1997). With the development of bioenergy conversion technologies globally, more and more commercial bioenergy products could be served for industrial

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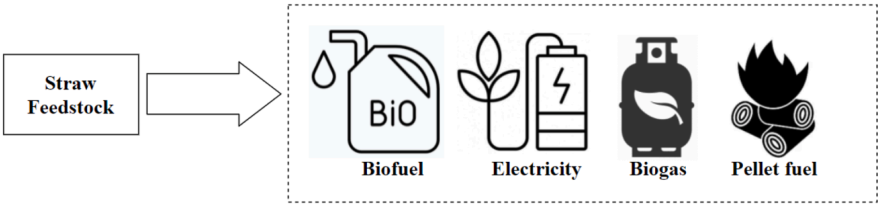

Fig. 1. The graphical illustration of bioenergy products from straw feedstock conversion.

and daily-life demand. The straw-based bioenergy products consist of electricity, biogas, biofuel (from biorefinery), pellet as well (See also Fig. 1). In China, electricity is the major bioenergy product, and biofuel will become progressively more important as time goes on. According to the "13th Five-Year-Plan of Biomass Energy Development" (National Energy Administration, 2016), in 2020, China is expected to produce 90 billion kWh bio-electricity, 8 billion metrics of biogas, 30 million tons of pellet fuel, and 6 million ton of biofuel. The bioenergy projects are increasing dramatically. Especially, straw could be regarded as a carbon-neutral energy source. This is because the amount of greenhouse gas released during straw utilization process is almost equivalent to carbon capture through photosynthesis while crop growing. Therefore, straw would play an important role in the transition of renewable and clean energy and achieving carbon neutrality in China by 2060.

Compared to food or energy crops, the initiative of using straw feedstock for bioenergy is entirely different, because straw has dual characters: waste and resource. After crop harvesting season, enormous straw is generated. Straw return could exacerbate crop pest infestation, weed and disease (Aguiar et al., 2021; Ren et al., 2019, and it also brings about extra costs (Yang et al., 2020), which are uneconomical for farmer. If straw cannot be disposed of properly, it will seriously affect next-season cropping. Hence, for developing countries (e.g., China, India), considering the negative effects of straw return, straw burning in the farmland is the cheapest and most convenient way to get rid of it (Roder et al., 2020; Hong et al., 2016). However, burning straw met with public opposition. Due to the atmospheric circulation, atmospheric pollutants generated from straw burning in farmland would also remarkably influence the public dwelt in urban areas. He et al. (2020) used clinical records and satellite fire data to reveal that straw burning in the farmland could result in the increase of cardiorespiratory disease in China. Concerning the harmful environmental hazards from straw burning as agricultural waste, using straw feedstock for bioenergy is turning waste into a valuable resource, and it can achieve the triple-win solution from agriculture, environment and energy simultaneously. This is one of the crucial advantages that government strongly supports the development of straw-based bioenergy industry. In addition, compared to conventional fossil fuels, using straw feedstock as an alternative can reduce greenhouse gas emissions. The evaluations from Nguyen et al. (2013) and Shafie et al. (2014) indicated that using straw for power generation has better performance than coal and natural gas in Denmark and Malaysia respectively. Similarly, life cycle assessment from Jiang et al. (2020) and Song et al. (2017) demonstrated that straw pellet is a promising alternative for coal utilization on cooking and heating in China. Straw-based bioethanol presents a remarkably lower greenhouse gas emissions compared to petrol (MacLean and Lave, 2003; Sheehan et al., 2003) and corn-based bioethanol (Leboreiro and Hilaly, 2011; Wu et al., 2006).

However, on the other hand, the cost of straw-based bioenergy products is relatively higher than conventional fossil fuels. In China's power generation industry, straw-based power plants are found to have weakly economic sustainability (Zhang et al., 2013; Wang et al., 2020), and they cannot compete with coal-fired power plants. For bioethanol production with higher requirement of technology (e.g., hydrolysis and fermentation), the production cost of bioethanol is too high (Talebnia et al., 2010), and unless with intervention from government (such as policy support in form of tax exemptions, subsidy), the price of straw-based bioethanol cannot compete with petrol (Littlewood et al., 2013). In regard to this, some studies attributed the weak competitiveness of straw-based bioenergy products to feedstock supply chain (Zhang et al., 2013; Wang et al., 2020). Straw feedstock cost accounts for between 40%−70% of total bioenergy production cost (Xu et al., 2020; Tan et al., 2014; Song et al., 2017; Cao et al., 2012; Chen et al., 2006; Ishii et al., 2016; Rentizelas et al., 2009a), depending on scale or energy type.

Straw-based bioenergy production is a typical example of a partnership between agricultural production (primary sector of the economy) and energy production (secondary sector of the economy). While many obstacles exist to the establishment and operation of bioenergy conversion plants (BCP), general worries influence their production, including the high physical volume of straw, costs inherent in collecting and packing straw from farmland, and expenses in shipping straw to BCP. Straw feedstock has the features of strong seasonal availability (Lovrak et al., 2020; Bhutto et al., 2017; Vera et al., 2015) and spatially sparse distribution (Sharifzadeh et al., 2015; Natarajan et al., 2016), the cost estimation of its supply is entirely different with conventional fossil fuel supply. In order to achieve the objective of reducing cost, model is a critical approach in strengthening understanding that leads to promoted straw supply chain efficiency. Gosens (2015) established a comprehensive database with information on 236 biomass power plants in China, and most of the projects did not report the supply cost of straw feedstock. This results in the uncertainty of cost estimation, which brings heavy financial risk in operation. Zahraee et al. (2020) emphasized that the expensive cost of feedstock and the unreliable supply chain are the major obstacles in bioenergy development.

Moreover, this bottleneck hinders the substitution of fossil fuel with straw-based bioenergy in energy-intensive industry and delays the target of achieving carbon neutrality in China. Conch Cement, the second-largest cement manufacturer in the world, tries to substitute coal with straw feedstock in cement production. A demonstration project in Anhui province was designed to consume 300 thousand tons of straw feedstock annually, in return to save 20% of coal consumption (Zhang and Zhang, 2021). However, in reality, the cost of straw feedstock supply is far beyond the expectation, and actual substitution rate only increased by 10%.

Straw feedstock could be utilized for bioenergy in various forms, and economic and life cycle assessment for renewable bioenergy has become an active and energetic domain of research in recent years. Hence, reliability and cost competitiveness of bioenergy production would rely significantly on straw feedstock collection and provision, simultaneously reducing the supply cost would be critical. However, how straw feedstock is supplied or delivered to BCP is full of knowledge blank and uncertainty. Until now, either from academia or industry, providing the relative accurate cost estimation of straw feedstock for bioenergy is lacking. To solve the realistic challenge in straw feedstock supply chain faced by China, and undertake the global responsibility of mitigating global warming by achieving carbon neutrality in time, this paper fills the knowledge gap in establishing a straw feedstock supply model that could satisfy the specific conditions in China and ensures a stable and reliable straw supply with optimal arrangements and minimum costs. This paper proposes an open-source & GIS-enabled linear programming

Table 1
Cost components comparison with other articles in the straw feedstock supply chain.

Article	Pur	Rak	Bal	Loa	Tra	Unl	Sto	Pre	Con	TP	PD	Country
Xu and Chen (2020)	√		√	√	√	√	√			√		China
Tan et al. (2014)	√		√	√	√	√	√			√		China
Sun et al. (2017)	√		√	√	√	√	√					China
Song et al. (2017)	√			√	√		√	√	√		√	China
Xing et al. (2008)	√		√	√	√	√	√					China
Yu et al. (2013)			√	√	√	√	√					China
Fang et al. (2014)			√	√	√	√	√					China
Huo et al. (2016)	√		√	√	√	√	√					China
Cao and Shen (2012)	√			√	√	√		√				China
Yu and Fan (2009)	√		√	√	√	√						China
Ma et al. (2015)	√		√		√				√			China
Chen et al. (2006)	√			√	√							China
Liu et al. (2019)	√		√		√							China
Zhang et al. (2009)	√		√	√	√		√			√		China
Wang et al. (2017)	√		√	√	√	√	√					China
Chen et al. (2012)	√		√		√		√					China
Delivand et al. (2011)	√		√	√	√	√	√					Thailand
Ishii et al. (2016)			√	√	√	√	√		√	√	√	Japan
Allen et al. (1998)			√	√	√	√	√	√				UK
Rentizelas et al. (2009a)	√			√	√	√	√	√	√		√	Greece
Hess et al. (2007)			√	√	√	√	√	√				US
Sokhansanj et al. (2006)			√	√	√	√	√	√				US
Rentizelas et al. (2009b)	√		√	√	√	√	√	√				Greece
Kadam et al. (2000)		√	√	√	√		√					US
Suh et al. (2011)				√	√	√						US
Wang et al. (2020)	√		√		√		√		√			China
Chiu et al. (2016)		√	√		√							China
Roy et al. (2012a)			√		√			√	√			Japan
StrawFeed		√	√	√	√							China

Notes: The abbreviation of column names are: Pro (Procurement), Rak (Raking), Bal (Baling), Loa (Loading), Tra (Transportation), Unl (Unloading), Sto (Storage), Pre (Pretreatment), Con (Conversion), TP (Target profit), PD (Product distribution).

model called StrawFeed for the simulation and optimization of various straw feedstock supply activities. For better interpretation performance, this paper chooses to use the open-source programming language R to compile the codes for model manipulation, which could help serve in different application situations in bioenergy production in China. The model is applied to case analysis of corn straw supply for power generation in Nongan county, Jilin province, China. The subsequent manuscript is arranged as follows: The next section reviews previous research in straw feedstock supply chain and motivations for formulating the presented model. Section 3 describes the StrawFeed model with technical details. Section 4 presents the results from case study and discusses the possible scenarios in straw feedstock supply chain. The final section draws an important conclusion and points towards future model extensions.

2. Literature review and motivations

The interest in the research and application of straw feedstock supply increased in the mid-1990s with a focus on corn straw in the US and Europe. These and other similar researches compared a series of various circumstances based on available data to decide the optimal solutions and recognize weaknesses. Now, China, India and other developing countries have become the primary research contributors to straw feedstock supply chain (Wang et al., 2021a). An integrated review of Calvert (2011) concluded that inadequate baseline information (e.g., the spatial-temporal distribution of biomass feedstock) prevented the relevant stakeholders (government responsible for promulgating sector-incentive policy; private investors engaged in bioenergy production) to make correct and responsible decisions. So, the integrated model is contrived that relevant stakeholders could be used to evaluate the sustainability performance of straw feedstock supply chain.

While emphasizing some of the critical issues in straw feedstock supply, the literature review is also helpful in recognizing the subsequent key issues, which have not been rigorously and thoroughly defined and explored:

2.1. *The system boundary of straw feedstock supply: cradle-to-gate*

The costs for straw-based bioenergy production could be divided into three components (Mol et al., 1997): feedstock procurement cost, supply cost for collection and transportation, as well as the cost for establishing and operating the bioenergy conversion plant. Each component has its unique feature. As for straw-based biomass feedstock, procurement is negotiating with farmers to obtain their permission for collecting straw resources. The emissions in different conversation technologies are distinct significantly (Biomass Energy Resource Center, 2009; BASIS, 2015; Niu et al., 2016). The greenhouse gas emissions in biogas-to-electricity are remarkably higher than straw-burning power generation (Said et al., 2020; Wang and Wang, 2020). On the contrary, liquid biogas used for substituting LGP could achieve greater potential greenhouse gas emissions reduction than straw-burning power plants (Soam et al., 2017). So, the separation and determination of system boundary in production, especially in feedstock supply and energy conversion and management stages, could be extremely useful to explain and clarify the uncertainty.

There are two major types of system boundary: cradle-to-gate and cradle-to-grave (Garcia and Freire, 2014; Proietti et al., 2013; Qin et al., 2016). Table 1 sorted out and summarized the representative researches of straw feedstock supply chain, they were selected based on the previous reference database (Wang et al., 2021a) and reported the monetary costs in detail (the criteria and procedure of literature collection and selection are clarified in supplementary). The cost components were classified according to the description and authors' judgment. It could be observed that the cost components incorporated in every supply chain are distinct significantly, and the clarification and determination of system boundary are necessary and crucial, which could result in the misleading of decision-making.

(1) Procurement cost

Procurement cost is a popular cost component in straw feedstock

Fig. 2. Example of a typical hayrake used in Jilin province (Photograph taken by one of the authors of the article).

supply chain (18 pieces of article, 62% of overall representative researches), and the procurement prices were diverse significantly, but the estimations were unified: the quantity of straw feedstock required to multiply by the procurement price. Procurement cost of straw feedstock is determined by the opportunity cost of alternative uses of straw, which are circumscribed by various situations and prices are changed dynamically.

Different farmers have distinct perceptions towards straw feedstock selling behaviors. Some farmers are more capable of disposing of straw resources in an eco-friendly manner; whereas for some farmers straw disposal seriously exploits their precious labor resources, especially during intense harvesting season (Wu et al., 2001; Xu and Yan, 2016; Feng, 2014; Huang et al., 2012). Long-term and excessive straw returning would bring negative impacts on crop production. It would increase crop disease prevalence, pest infestation and weed germination (Aguiar et al., 2021; Ren et al., 2019. The farmers have to raise expenditures for more pesticides and labor. In addition, low temperature makes straw uneasy for decomposing and biodegradation (Li et al., 2018; Kuang et al., 2014), which would impede the root penetration (Li et al., 2018) in the cold regions. Multi-year consecutive straw returning may decrease crop yield (Kadam et al., 2000). The field survey from Huang et al. (2019) showed that some farmers doubt that straw incorporation would increase the crop yield, and another field survey from Yang et al. (2020) showed that full straw incorporation is not welcomed by farmers. These unfavorable factors frustrate the farmers' enthusiasm for straw return. In this circumstance, some farmers are unwilling to sell their straw resources, whereas some farmers have a strong enthusiasm to dispose of the straw in the most convenient way. In the areas with abundant straw production and lack of efficient disposal way (e.g., cold and dry weathers would decrease straw decomposition rate and thus is unfavorable for straw incorporation as organic fertilizer), the farmers are even willing to pay for cleaning the farmland with straw removal, especially under the strict ban of straw burning in the farmland. In such situations, the price of straw feedstock is negative (BCPs could earn extra revenue from straw feedstock collection from farmers, Junginger et al. (2001)). Since it depends too much on the outcome of negotiations with local farmers, in IBSAL model (Integrated Biomass Supply Analysis and Logistics model developed by Oak Ridge National Laboratory), the procurement cost of biomass feedstock was excluded (Sokhansanj et al., 2006; Kumar and Sokhansanj, 2007) borrowed the parameter of procurement from other literature, and added it to overall supply cost additionally. So, it could be estimated independently, and could not be optimized through straw feedstock supply chain.

(1) Raking

It is astonishing that, except for Kadam et al. (2000), Chiu et al., 2016 and StrawFeed model, raking activity is ignored in most of the studies (3 pieces, 10%). The application of mechanical harvesting with combine harvesters could reduce the labor force requirement and alleviate the farmers' burden in crop production, and become popular in both developed and developing countries. But it results in the straw spread out in the farmland (Nguyen et al., 2016). Raking with hay rake could gather and concentrate the straw together, which could speed up the working efficiency for baling, and preserve the quality and structure of the baled straw. Hay rakes are widely used in China (See also Fig. 2) and the US. Although the cost of raking only accounted for a small proportion of overall straw feedstock supply cost, it is necessary to point out this omission in terms of the completeness of the straw feedstock supply chain and to enlighten the future estimation with caution.

(2) Baling

Now, baling is the common practice in straw feedstock supply chain (24 pieces, 83%), and this is largely due to mechanical collection, which is gradually substituting manual collection by farmers directly. In comparison with the loose straw, baled straw is more compressed, which is beneficial for transporting with lesser volume, and more easily managed in warehousing. The mechanical operation could reduce labor force requirement dramatically (Nguyen et al., 2016), and the working efficiency in mechanical collection is significantly better than manual collection, and thereby the unit cost could also be lower (Sun et al., 2017). The mechanization also raises the entry threshold in straw feedstock supply chain. The local farmers cannot afford the investment cost for baling, which promotes the level of specialization. BCP could also reduce the transaction costs by negotiating with brokers instead of massive farmers.

(3) Transportation

Transportation is an indispensable activity in every supply chain (100%). So, how to reduce the cost and improve the working efficiency in transportation activity attract the most interest. (Ko et al., 2018) and Wang et al. (2021a) both reviewed the current literature on transportation activity in biomass feedstock supply chain and provided the constructed suggestion on how to promote the reliability and sustainability of transportation activity.

(4) Storage

Whether to incorporate storage activity (20 pieces, 69%) is decided by the acquisition modes selected by BCP. There are two common straw feedstock acquisition modes in China: self-acquisition mode and broker acquisition mode (Wen and Zhang, 2015). For self-acquisition mode, the responsibility of straw feedstock provision should be fully undertaken by BCP, and they require to establish and operate supply chain. They have to purchase straw feedstock from local farmers directly and accomplish the activities independently. By adopting this mode, all cost components in the supply of straw feedstock should be included in cost accounting. In broker acquisition mode, BCP outsources the straw feedstock supply work to the broker. Brokers are local farmers who have a commercial mind and good communication capacity. They believe that providing service between farmers and BCP could earn more money than agricultural production. They have a good personal relationship with local farmers, and could more easily collect straw feedstock from farmers (Wang et al., 2021a). BCP do not involve in the intermediate activities, and they wait and receive straw feedstock at plants. Under such circumstances, brokers would not undertake the work for storage, because the system boundary for them is "cradle-to-gate": their work would be terminated when their feedstock provided is weighted and passes the quality inspection. The cost component of storage would be excluded from straw feedstock supply in broker acquisition mode. Storage cost could be calculated by the quantity of straw feedstock required (Sun et al., 2017), or it could be further simplified by a fixed cost for calculation. Kadam et al. (2000) assumed that the storage cost is 4.5 USD for every ton of rice straw in California, US.

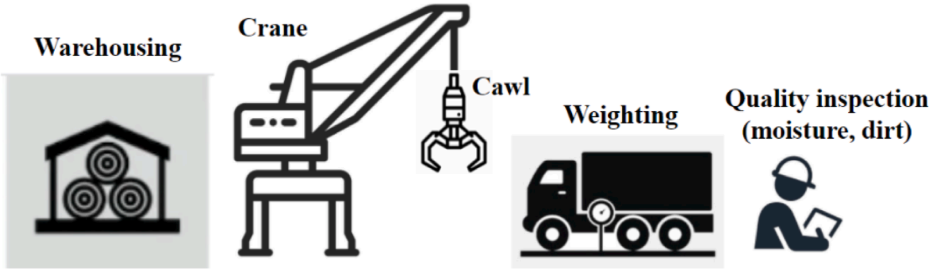

Fig. 3. Graphical illustration of unloading and delivery-to-warehouse activities by large-scale BCP.

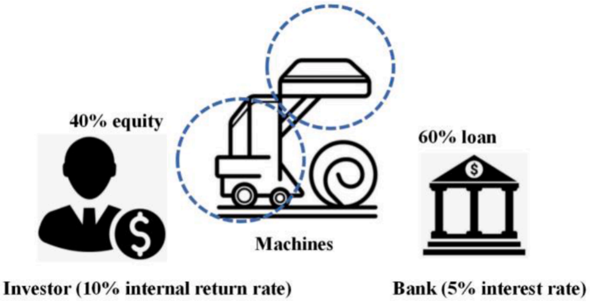

Fig. 4. The graphical illustration of capital investment adopted from Lin et al. (2013).

(5) Loading & unloading

Similar to storage activity, BCP are responsible for unloading activity (18 pieces, 62%) in broker acquisition. After straw feedstock is transported to the plants, it would be unloaded and managed with cranes and stacked into the warehouse in order (See also Fig. 3). For the large-scale BCP with crane equipment, the cost of unloading activity is much cheaper. Loading feedstock in the field should be conducted simultaneously due to the limited time period, whereas the transportation fleet arriving at BCP should queue up for unloading, and proper amount of unloading machines (forklifts or loaders) could satisfy the need. Hence, some researchers treated the cost in unloading activity was identical to loading activity (23 pieces, 79%), which may result in the overestimation. Alternatively, Kadam et al. (2000) neglected the cost estimation in unloading activity, and they believed that straw feedstock could be "dumped" from the trucks.

(6) Bioconversion and product distribution

Some studies indicated that the straw feedstock supply chain is the subordinate link of straw-based bioenergy production system, and the costs in production stage, include pretreatment (drying, grinding, cooling etc.) and bioconversion (briquetting for pellet fuel or power generation for electricity) are estimated. However, (Song et al., 2017; Ishii et al., 2016; Rentizelas et al., 2009a) further expanded the system boundary on product distribution (selling) stage. Song et al. (2017) and Ishii et al. (2016) estimated the costs of delivering pellet fuels (from corn and rice straw) to consumers respectively. Rentizelas et al. (2009a) calculated the costs of electricity transmission and distribution networks. Hence, the inconsistency of system boundaries would have a remarkable influence on the outcome, and the comparison between different studies should with careful consideration (Soimakallio et al., 2011).

(7) Target profit

Target profit is a novel argument in straw feedstock supply chain (4 pieces, 14%). In most cases, the investment does not consider the rate of return on capital. In fact, if the straw feedstock chain is regarded as an independent commercial operation, the investors also claim the profit (interest) from the investment, apart from investment recovery. Taking a concrete example, Lin et al. (2013) contrived a hypothetical scenario in which bioenergy investors held 40% equity, and the remaining 60% of the overall capital investment comes from business lending (e.g., bank load or enterprise bond). Furthermore, occupancy expenses for these two different sources are distinct: the internal return rate from bioenergy investors was 10%, but the interest rate from load is 5% (See also Fig. 4). The occupancy costs for investment should be considered because the capital was not given gratis, and the target profit could be estimated independently. However, it is improper to treat it as a cost component. The critical issue to ensure the sustainable operation of the straw feedstock supply chain is how to allocate the target profit among the stakeholders (farmers, brokers, investors).

(8) Transparency

One of the major obstacles to hinder the application of previous modeling in biomass feedstock supply is the transparency of simulation process. For some feedstock supply articles (Cao et al., 2016; Panichelli and Gnansounou, 2008), the components in the supply chain did not elaborate, and the selection of key parameters was not reported. The technical and mathematical details are seldom disclosed, and their applicability is somewhat restricted due to the lack of reproducibility. It is hard to reproduce or reuse the simulations from some existing researches. Therefore, the transparency is then beneficial for inspection of cost estimations, and the experience and lessons learned from other related researches could be helpful to check the completeness and consistency of the supply chain. For example, for mechanical collection, loading baled straw feedstock is indispensable before transportation, where it is neglected in some studies, and it could be suspicious that the carelessness may result in cost underestimation.

Nowadays, most of simulations rely on computer programming, which could increase efficiency significantly. However, studies rarely report specific computer software used for programming, let alone provide the original codes for reproducibility. This would be harmful to reusing the simulations for a specific application and hinder further improvement and optimization. Also, Latterini et al. (2020) argued that compared to relying on costly commercial software, using open-source software could be more user-friendly. It could achieve personal extension, such as adding harvesting operation analysis in feedstock supply chain. Thus, using open-source software, such as R language, is becoming an increasingly preferred choice. According to the definition from Open-Source Initiative, open-source software allows the user freedom to run, review, alter, enhance and modify the code for any purpose (Engard, 2010; Open Source Initiative, 2020). Such advantages would be particularly beneficial for simulation and modeling. Open source could provide the users with a step-by-step guidance on how to calculate each number, and make the results more plausible and comparable. The users could learn directly from the public source codes, and even make modifications to satisfy their personalized needs. Compiling the codes for simulation of straw feedstock supply with open-source

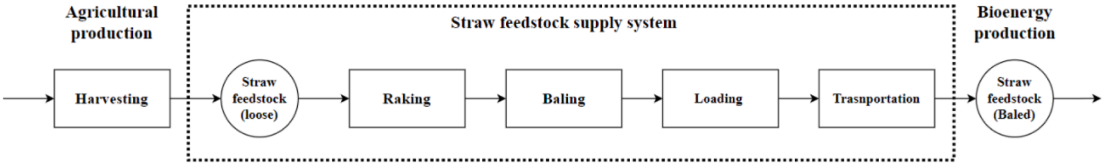

Fig. 5. The components and technical details in straw feedstock supply model (StrawFeed).

software could make the analysis be both transparent and highly reliable in the long run basis, and the transparent methodologies for bioenergy planning would be more possible to output the correct solutions (Zubaryeva et al., 2012).

(9) The system boundary in StrawFeed model

The full production chain of bioenergy production is complicated, and thus many simplifications, as well as approximation and system boundary settlement, are necessary to reduce model complexity (Nilsson, 1999). This paper concentrated on the supply activity (cradle-to--gate), because cradle-to-gate boundary is a more realistic option, and gate-to-grave data is often not readily available. As in China, straw feedstock supply is the bottleneck that restricts the development of straw-based bioenergy production, and broker acquisition mode is gradually becoming the mainstream that substitutes self-acquisition mode. The simulated results from StrawFeed model could serve for analyzing interaction of stakeholders among farmers, brokers, and BCP with the cost components of procurement price and target profit. StrawFeed model also fills the knowledge gap of the absence of a sustainable and reliable straw feedstock supply model that could incorporate economic, environmental and social dimensions.

Fig. 5 shows the overall scope and the important components of the StrawFeed model, where the ellipse represents the materials, the circle represents middle-term and finished products, and the rectangle represents activities. The model focuses on the feedstock collection and provision activities. Straw feedstock supply could be classified into the following different tasks: (1) Raking. After harvesting, straw is scattered in the field, and it is hard to collect. Using hayrake could gather scattered straw together. (2) Baling. The low-density straw feedstock could be compressed into bale (hay) by balers. (3) Transportation. Road-travelling is carried out using a set of trucks. (4) Loading. Loading straw feedstock to trucks by forklift. In the past, straw feedstock was collected by local farmers artificially. A detailed description of StrawFeed model would be declared in Section 3.

2.2. *The challenges and opportunities in straw feedstock supply chain in China*

Apart from baseline research, scenario analysis is also useful for revealing comprehensive circumstances in straw feedstock supply chain (Palmieri et al., 2017). This manuscript contrives four scenarios that reflect the potential challenges that may impair profitability, and the potential opportunities that could reduce the supply cost, where the policy instruments in China are considered:

2.2.1. *Weather sensitivity*

Straw collection and transportation could only be processed after crop harvesting, and with the time passed, the quality of straw feedstock in fields would be lost gradually. So, the time for straw feedstock is restricted and urgent. But the weather (e.g., rainfall, snowfall, strong wind etc.) would significantly delay the working efficiency and impair the sustainability of straw feedstock supply chain (Kaylen et al., 2000). Rain and snow would hinder baling and transporting corn straw, thereby reducing the limited working days. Rain has double unfavorable effects on straw supply, which not only influence the working efficiency of the facility, but also results in straw that is too wet to bale. Also, the rain would turn the field become muddy and soggy, thus restricting the tractors' mobility. Under the heavy rain, the common-use wheeled tractors may not be functional, and they have to be replaced with crawler tractors, which would impede working efficiency and bring extra cost. Besides, the rainfall would be absorbed by the straw, and it would be uneconomical to transport "water" in the straw. The BCP would reject the procurement of the straw with moisture higher than 17%. Although these risks have been acknowledged in the literature, their damage to sustainable supply and supply cost has not been quantified.

There are several studies that assessed the influence of weather on agricultural production. Seldom studies, however, examined the concrete influence of weather change on straw feedstock supply, which is highly related to agricultural production. Nilsson (1999) and Sokhansanj et al. (2006) examined the direct influence of weather on straw feedstock supply, and gave the quantity criteria of relationship of participation/snowfall and affected working day/hour. Mapemba et al. (2008) believed that the conventional supply models did not recognize the feedstock harvest days are restricted by weather, and the ignorance of weather constraints may result in the inexactitude estimation of supply cost. So, it is necessary to incorporate weather variation in straw feedstock supply chain, to give a clear answer for how it would impact the supply cost, thereby influencing the decision-making.

Scenario1. Identify the impact of weather change delay time period of straw feedstock supply.

2.2.2. *The competition use of straw feedstock*

Instead of full straw return or straw burning in the farmland, an optimal scheme of straw utilization is proposed, which is more attractive for farmers. Systematic analysis from Wang et al. (2021b) indicated that straw incorporation could significantly increase the crop yield than straw removal from farmland. If the proportion of straw returning is at a reasonable level, straw would be the organic fertilizer, which is beneficial for promoting soil fertility and increasing crop yield.

In straw-based biomass industry, the competed use of straw feedstock was fully aware by many researchers, and feedstock availability should be assessed and discussed beforehand. Soil protection and conservation is the major source for straw utilization, and it is also the most accessible source to be quantified. Because the incorporation of straw as organic fertilizer into soil is an agronomic practice that is comprehensively studied, and such evidence from agricultural experiments provide the guidelines that could assist the quantification of straw feedstock. Borjesson and Gustavsson (1996) believed that in Sweden, only 2 tons per ha of straw feedstock were available for bioenergy production, and the remaining part would be used for animal husbandry sector as well as incorporated into farmland to preserve soil fertility. Kadam et al. (2000) believed that full straw removal would bring soil nutrient depletion, which required additional nutrients amendment to compensate for this loss. Considering that straw mulching on erodible land has the function of preventing soil erosion, Kaylen et al. (2000) gave a conservative assumption that only 10% of crop straw could be utilized for straw-to-ethanol production in Missouri, US. Banowetz et al. (2008) utilized USDA NRCS soil conditioning Index Worksheet to estimate that the mean proportion of straw incorporation was approximately 4480 kg/ha, and they further calculated that available (cereal) straw feedstock for bioenergy utilization in the Pacific Northwest represented one-third of total straw production. Based on the function of decreasing

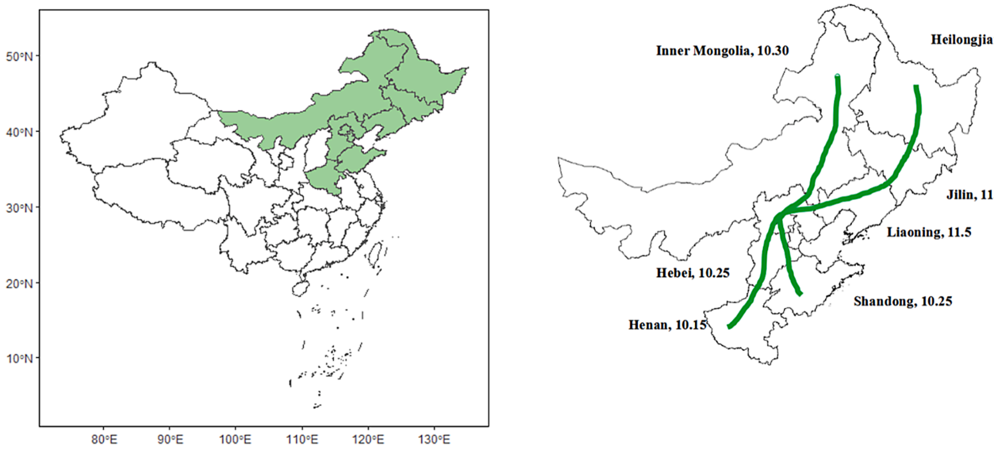

Fig. 6. The schedule of corn harvesting and mobility of agricultural machines in North China. For (Henan, 10.15), the former is the province's name, and the latter is the expected date of corn harvesting.

water loss and soil erosion, Liu and David (2014) estimated demand of soil on corn straw on a national scale. Liska et al. (2014) argued that removal of corn straw for biofuel production might lead to reduced soil organic carbon and increase greenhouse gas emission in US corn belt. Menandro et al. (2019) conducted field experiments to investigate (sugarcane) straw removal effect on soil health and ecosystem services in Brazil. The results indicated that full straw removal may cause soil compaction and impair soil biodiversity. So, they suggested that partial straw removal could be a strategic measurement to balance the requirement of soil health protection and straw feedstock sustainable provision. Also, Banowetz et al. (2008) pointed out that the competing use of straw feedstock, for instance, fodder and bedding for dairy production enterprises are preferable.

The benefits of maintaining soil organic carbon stocks and other ecological service functions have been analyzed thoroughly, but few have estimated the economic loss in lesser straw feedstock supply compared with full straw removal, as required by the profit maximization guided to commercial bioenergy enterprises.

Scenario2. Compare the different straw amounts that were removed from farmland (full/half).

2.2.3. *Cross-regional operation of machine*

Straw supply chain is strongly dependent on agricultural production, so it has seasonal restrictions. China is located in the Northern hemisphere, where crops mature from south to north. After satisfying the local needs of harvesting, the idle agricultural machines could be moved to the north. Such movement would cross multiple administrative regions, so it is called cross-regional operation of agricultural machines (Ren et al., 2020; Yang et al., 2013). The movement path of agricultural machines could be estimated based on the harvesting time in different regions (See also Fig. 6). This operation mode could promote utilization rate of agricultural machines, and also improve the spatial spillover of agricultural mechanization (Zhang et al., 2021).

In the past, the poor traffic conditions in rural areas hindered the mobility of agricultural machines. Nowadays, the transportation conditions have been promoted, especially in the rural areas. Furthermore, the Chinese government has also promulgated the incentive policy for free transportation fee of agricultural machines engaged in cross-regional operation by highway (Zhang et al., 2014, 2017; Ministry of Transport, 2020). Such measures remarkably reduced financial burden for cross-regional operation of agricultural machines.

On the other hand, the amount of agricultural machinery was restricted, and the regional deployment was unbalanced. In 2011, there were only 13.5, 1.4 and 6.8 thousand balers in China, Northeast China and North China respectively. With the vigorous development of the manufacturing industry, agricultural machines are no longer in short supply. The number of balers is increasing dramatically in general, but the growth in Northeast China and North China is significantly lower than the national level (See also Fig. 7). So, BCP in Northeast and North China could be beneficial for importing balers from other regions. Such internal mobility of agricultural machinery could alleviate the machine shortage during the harvesting season, and the owner could earn more profit from the machinery rental. In general, previous proposals to supply straw feedstock for bioenergy production have not been economical due to the costs involved in the huge investment for machine procurement. In cases where cross-regional operation is plausible in China, hiring machines may provide an appropriate choice to reduce the supply cost, where the machines could be fully utilized and the idle time could be diminished.

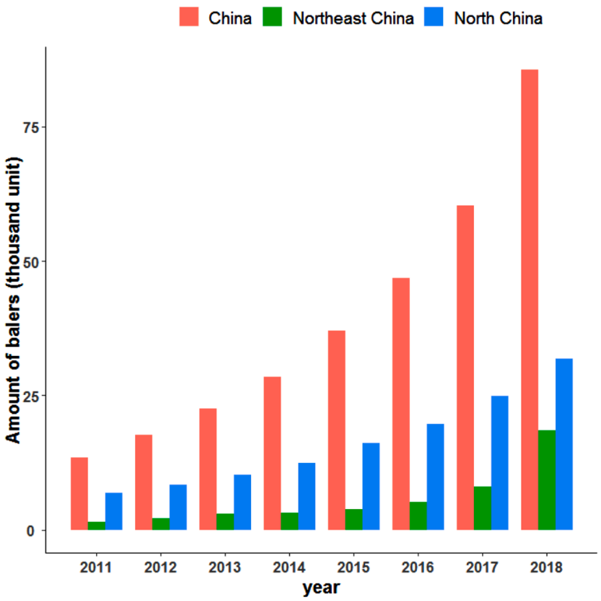

Fig. 7. The holding number of balers in China, Northeast China (Heilongjiang, Jilin and Liaoning provinces) and North China (Hebei, Shandong, Shanxi, Henan, Inner Mongolia provinces). The data are from CAAMM (2012-2019).

Scenario3. Assess the impact of hiring machines, where depreciation based on tenancy was analyzed.

2.2.4. *Exclusive machine procurement subsidy for farmers*

Because straw comprehensive utilization could be beneficial for reducing straw burning in the farmland, thereby mitigating atmospheric

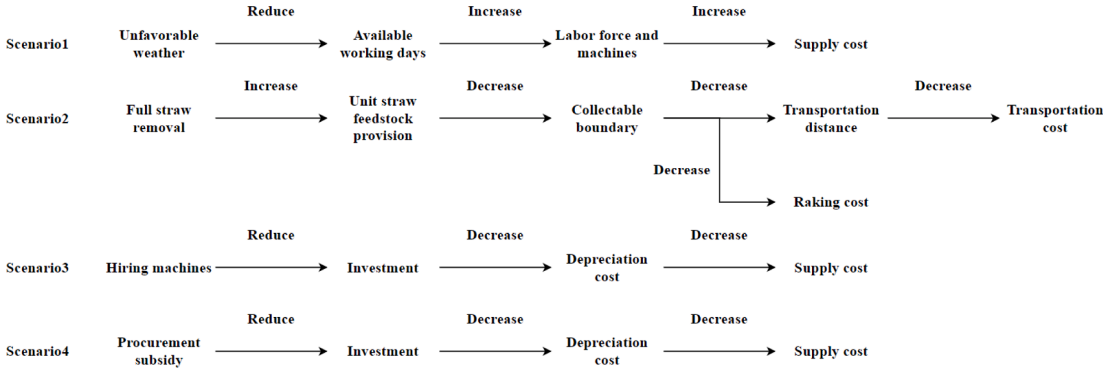

Fig. 8. The workflow of how parameters changed to influence the supply cost in each scenario.

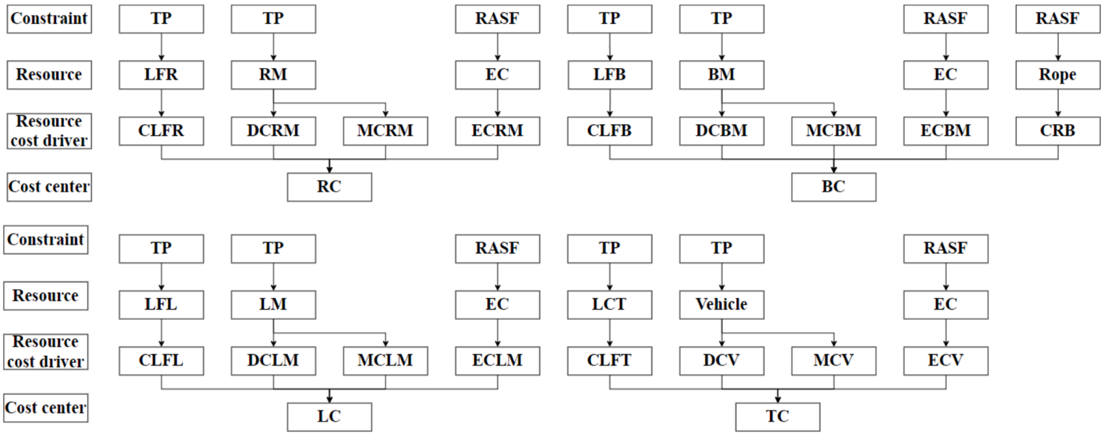

Fig. 9. The components and description of StrawFeed model based on activity-based costing methodology. The abbreviations are listed as follows: (1) Constraint. TP: Time period; RASF: Required amount of straw feedstock; DFB: Distance between farmland and BCP. (2) Resource: LFR: Labor force recruitment for raking; RM: Raking machine; EC: Energy consumption; LFB: Labor force recruitment for baling; BM: Baling machine; LFL: Labor force recruitment for loading; LM: Loading machine; LFT: Labor force recruitment for transportation. (3) Resource cost driver: CLFR: Cost of labor force recruitment for raking; DCRM: Depreciation cost for raking machine; MCRM: Miscellaneous cost for raking machine; ECRM: Energy consumption for raking machine; CLFB: Cost of labor force recruitment for baling; DCBM: Depreciation cost for baling machine; MCBM: Miscellaneous cost for baling machine; ECRM: Energy consumption for loading machine; CRB: Cost of rope for baling; CLFL: Cost of labor force recruitment for loading DCLM: Depreciation cost for loading machine; MCLM: Miscellaneous cost for loading machine ECLM: Energy consumption for loading machine; CLFT: Cost of labor force recruitment for transportation; DCV: Depreciation cost for vehicle; MCV: Miscellaneous cost for vehicle; ECTM: Energy consumption for transportation vehicle. (4) Cost center: RC: Raking cost; BC: Baling cost; LC: Loading cost; TC: Transportation cost; SC: Supply cost.

pollution and promoting economic growth, the government is advocating for introducing straw utilization projects. It is reported that, in Jilin province, nearly 100 biomass-based power plants are under construction or in operation (Beijixing, 2019) . Also, in order to achieve the goal of clean air, coal is restricted and straw pellet is an important energy source alternative for satisfying the heating demand, especially for the areas experiencing long and cold winter. Straw pellet has great market demand. So, some BCP choose to own the machines to ensure reliability and supply security. On the one hand, they are worried about the competition of intensive demand for rental machines, especially the time period of straw supply is fixed and limited. On the other hand, the dynamic and continuous operation of agricultural machines from cross-regional work would increase the failure rate, thus affecting the straw supply efficiency.

In China, in order to raise the mechanization level and motivate the willingness to use agricultural machines, the government provides subsidies for agricultural machine procurement. In straw supply chain, balers and tractors could be beneficial from government subsidy (Ministry of Agricultural and Rural Affairs, 2019). However, the subsidy is only granted to farmers, and BCP cannot apply (National People's Congress, 2005). Therefore, instead of purchasing hayrakes, balers and tractors directly, the incorporation with brokers could reduce the procurement cost.

Scenario4. Identify how the pursuit of procurement subsidy for agricultural machine impact feedstock supply cost.

The pathways of the influence from the change of parameters on final straw feedstock supply cost from these four scenarios are summarized and illustrated in Fig. 8.

3. Model description

In order to clarify the StrawFeed model more clearly, an accounting methodology, activity-based costing, is introduced to promote the accuracy of straw feedstock supply cost information. The activity-based costing methodology has been adopted by energy industries (Oh and Hildreth, 2013; Korpunen and Raiko, 2014; Kaiser, 2019; Tinoco et al., 2021). The whole straw feedstock supply process could be modularized, and the description of this methodology application is shown below in Fig. 9. The activity-based costing methodology is particularly useful in scenario analysis, which provides a clear logic chain for how to change the specific parameter that would impact the eventual supply cost.

3.1. Model inputs

3.1.1. Raking and baling

StrawFeed model could simulate collection activities of raking and

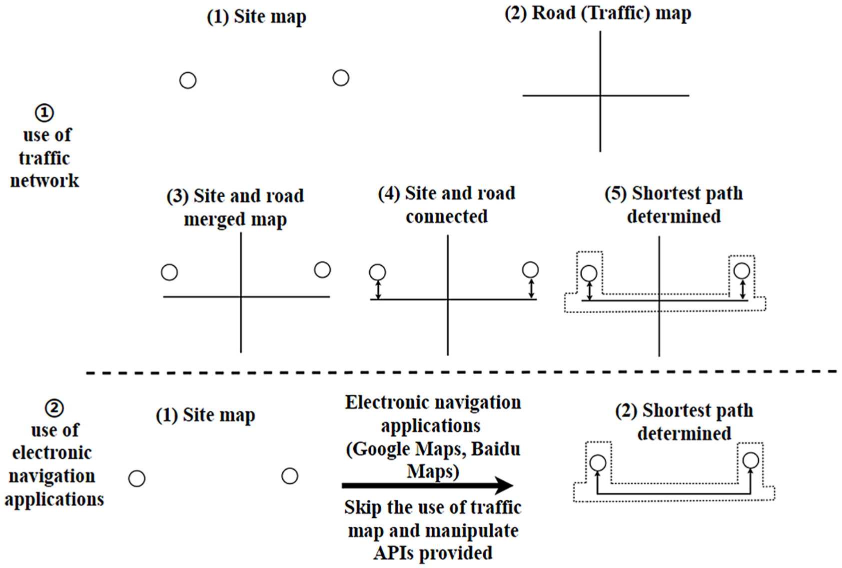

Fig. 10. A simplified example demonstration to compare the use of traffic network and electronic navigation applications.

baling for each farmland. The selection of the necessary machines could be optimized by StrawFeed model, and the collection working efficiency is restricted by the capacity of the chosen machine. Straw feedstock collection is first by raking, and the raked straw could be baled and directly sent to BCP. The selection of a suitable machine is a crucial decision for straw feedstock supply because of the availability of a series of current and innovative technologies. The collection cost comprises the amortized capital cost representing the procurement of hayrakes, balers, and tractors (power source for dragging hayrakes and balers), as well as the operating cost including drivers, energy consumption, maintenance, insurance and repairs. The energy consumption is determined by the required amount of straw feedstock which is known as a-priori and the energy consumption rate. The calculation procedures for the unit cost of straw feedstock in collection activity are shown in supplementary.

3.1.2. *Transportation*

Transportation tasks include in-field transportation such as roadside of baled straw feedstock as well as long-distance transportation between farmland and BCP. Due to the soggy and muddy conditions of farmland, in-field transportation cannot be overlooked. Unlike the previous assumptions or applications that either dragging baled straw feedstock to the roadside and loading it with forklifts (it also requires ground-harden surface), or using shovel loader but with lower working efficiency, StrawFeed model adopts off-road (rough-terrain) forklifts that could overcome the difficulty in in-field transportation and loading simultaneously. It is not only popular in China, but it is also exported to other countries. For long-distance transportation, StrawFeed model mainly considers road transportation using trucks, but it could also incorporate river, sea or railway transportation if appropriate. This could enable StrawFeed model to determine the optimal logistic arrangements as well as optimize the vehicle selections and combination. Transportation working efficiency is circumscribed by the carrying capacity of vehicles. The transportation and loading costs comprise the amortized capital cost representing the procurement of vehicles and off-road forklifts, and the operating cost includes drivers, energy consumption (diesel), maintenance, insurance and repairs. The energy consumption for transportation depends on the distance between different destinations, as well as the energy consumption rate of the vehicles.

The length of idle time also impacts the straw feedstock supply cost. Different from the collection activity of scattered operation in farmland, the transportation activity involves delivering and concentrating straw feedstock in one centralized BCP. Therefore, when a large number of transport vehicles is required or local transportation infrastructure is insufficient, it may cause traffic congestion and postpone delivery efficiency. In addition, if the straw feedstock handling activity (unloading, moisture testing, weighting) associated with the transportation is operating simultaneously, it would also prolong the truck idle time and thereby increasing the supply cost, which should be taken into consideration (Yu et al., 2010). Referring to other literature (Sun et al., 2017), StrawFeed model simplifies the complicated situation of idle situation and assumes that the idle time in transportation activity is 0.5 hour for every round trip. The calculation procedures for the unit cost of straw feedstock in transportation activity are shown in supplementary.

3.1.3. *Spatial distribution of straw feedstock in farmland*

There are three common practices to allocate the straw feedstock in farmland: assumption of uniform distribution; utilization of existing land cover dataset; applying of remote sensing technology (Wang et al., 2021a). Uniform distribution would shorten the transportation distance between fields and bioenergy factories, thus underestimating the cost of straw feedstock supply. With the progressive development of remote sensing technology, the precision of land cover classification is also promoted. Using the dynamic high-resolution satellite image, the information could be updated simultaneously. Banowetz et al. (2008) recognized the importance of evaluating the spatial distribution of straw feedstock, and they emphasized that remote sensing technology with high-resolution data is necessary to determine the density of straw feedstock (due to the unbalanced distributed straw feedstock within counties). Ahamed et al. (2011) reviewed the state of art of remote sensing technology on biomass feedstock production as well as its future policy implementation. Therefore, it is suggested that remote sensing technology could become the submodel embedded in the StrawFeed model. It could provide the geographical coordination of farmland, which could be useful for estimating transportation distance and facility site location optimization in advance.

3.1.4. *The distance estimation*

The evolution of various distance estimations for straw feedstock supply was reviewed by Wang et al. (2021a). The conventional Euclidean distance is convenient because it is the simplest method to calculate the distance between farmland and BCP with geographic coordination. However, the traffic journey could not be straight line due to the traffic obstacles such as mountains and buildings that could impact the structure of the traffic network (Laasasenaho et al., 2019). To reflect such a bending journey, the tortuosity factor could be used, which is ranging between 1 and 3.16 (Sultana and Kumar, 2014), but to select the correct or appropriate value is too case-specific. Consequently, manipulating traffic network data with GIS software (e.g., ArcGIS) is the popular way for finding the appropriate traffic route of straw feedstock supply. The gist of manipulating traffic networks is merged with different map layers. A simplified example demonstration is shown as follow (Fig. 10). To begin with, the site map is given when the locations of starting (farmland) and destination (BCP) are determined. And then, import the traffic network into software and overlay the two maps into one map. Next, connecting the site locations to their nearest traffic network, and a geometric traffic network could be created, and the shortest pathway between farmland and BCP could be decided with various algorithms (Liu et al., 2017; Kuisma et al., 2013; Wang et al., 2021a) at the end. In addition, the timeliness of the traffic network is another concern, especially in the fast-growing developing countries where the traffic infrastructure is promoting rapidly. The obsolete data may affect the performance of transportation distance. Hence, it is recommended to use electronic navigation applications that could solve these drawbacks. When the site locations with geographic coordination are given, the optimal pathway with dynamically updated information could be returned, based on the different constraints (shortest transportation distance with priority of using tollway or longer journey with avoiding tollway, etc.). Now, this computerized operation service is easily manipulated with APIs that released by these electronic navigation applications. Therefore, instead of rewriting and compiling the new way and codes for optimal pathway selection for straw feedstock transportation, using the services from Google Maps or Baidu Maps could receive better performance in distance estimation.

3.1.5. *Time period of straw feedstock supply*

The straw feedstock is only available after crop harvesting. Theoretically, the time period for straw feedstock supply starts from crop harvesting to field preparation for the next-season crop. Time period for single-cropping system is remarkably longer than multiple-cropping system. Also, long-time exposure to straw feedstock would bring dry matter loss, and fungi generated would cause hygiene problems and deteriorate the quality. So, the field is not the proper place for straw feedstock storage, and it should be collected and removed to the centralized and covered storage in bioenergy factory on time. In StrawFeed model, the working efficiency of straw feedstock supply is constrained by available working days (time period), which are determined by the users according to the feedstock requirement.

3.2. *Objective function*

The StrawFeed model currently uses a cost-based objective function. The objective function is then formulated as the minimization of the total cost for the straw feedstock supply chain which is represented as:

Objective = (Raking_cost+Baling_cost+Loading_cost+Transportation_cost)/required_amount_of straw_feedstock

4. Model application: corn straw supply in Nongan county, Northeast China

4.1. *The background information of case study region*

StrawFeed model could potentially be used to analyze the provision of any type of straw feedstock in any geographical area subject to the availability of data. This work applied the model to a hypothetical case of corn straw supply in Nongan county, Northeast China (See also Fig. 11). The selection of corn straw was motivated rudimentary by the profound amount of corn straw produced in China but lacked sufficient utilization patterns. Corn could not only satisfy the food demand, but it is also the important raw material for feeding animals and food processing. Domestic corn production is not enough. According to the prediction report, China would import 22 million tons of corn in 2021 (Chinese Agriculture Outlook Committee, 2021). Chinese authority plans to expand the corn sowing area to cope with potential food shortage. It is announced that, Huang-Huai-Hai region (another major corn production region in China) and Northeast China would increase 660 thousand ha of corn land (Ministry of Agricultural and Rural Affairs, 2021). Moreover, the selection of Northeast China as the geographical area is because it is praised as one of the corn belts in the world, whereas the competing capacity against the Midwest corn belt in the US. In addition, in comparison with other corn cropping areas in China, the farmland resource endowment is much better, with flat terrain and concentrated farmland as well as a relatively low rural population. Therefore, it is suitable for developing family farms with a high mechanization degree of crop production in high corn commodity rates. These advantages are also favourable for the construction and operation of straw feedstock supply chain. In addition, the corn cropping system in Northeast China is one crop per annual, so BCP could have a longer time period for straw feedstock collection and transportation. The county is a crucial administrative unit in China (Long et al., 2021). It undertakes the major task for agricultural production that could provide adequate straw feedstock for large-scale bioenergy production. It has an industrial foundation and demands for bioenergy products to some extent. Also, the county has proper administrative power to manage and supervise the operation of BCP, and provide incentives and motivation policy. Therefore, it is no doubt that the potential for straw-based bioenergy development at county level is significant and the demand is urgent.

On the bioenergy production side, producers prefer to preserve constant and uniform quality of feedstock (Lin et al., 2013). The reason why Nongan county was chosen as the study area is that corn yield in this county is the highest among other counties in Northeast China, with a sowing area of 338,299 ha and 2,349,102 tons in 2018 (See also Fig. 12). Also, the annual corn production and sowing area in Nongan

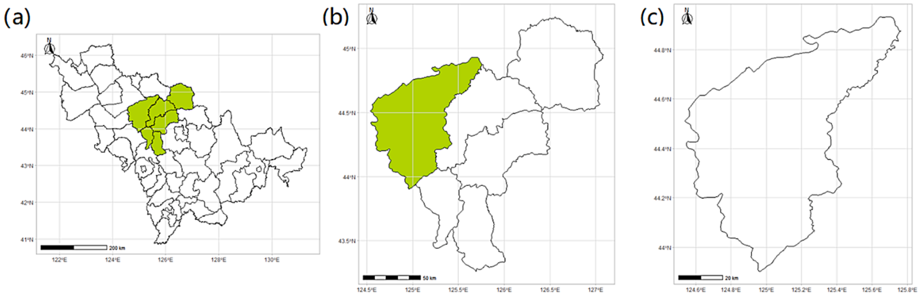

Fig. 11. The geographical illustration of case study. (a) Jilin province (regions filled with green color is Changchun city); (b) Changchun city (region filled with green color is Nongan county); (c) Nongan county.

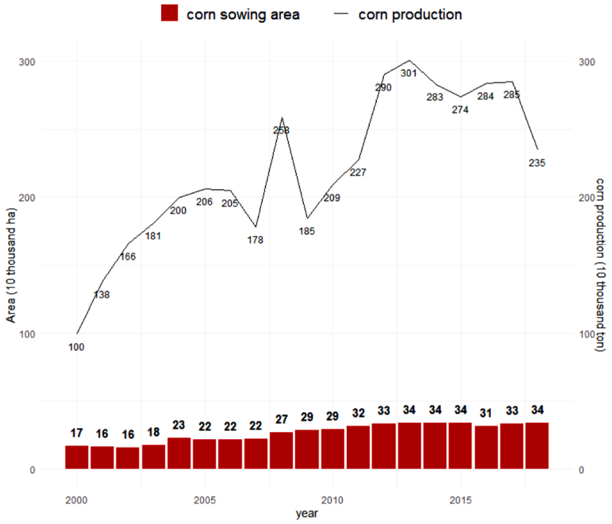

Fig. 12. The corn sowing area (line) and production (bar) in Nongan County. The statistical data are from Statistic Bureau of Jilin (2019).

county have increased steadily since 2000 and remained stable since 2010. So, it is regarded as a major corn production county in Northeast China. Besides the current and short-term leading production of straw feedstock, the long-term assessment for local cropping structure is very important and useful. For instance, cassava stalk was discarded from the consideration for bioenergy production in North Thailand, because of the gradually decreased production over 10 years (Junginger et al., 2001). The historical data of corn production in Nongan county showed a booming trend, so the long-term stable and sustainable straw feedstock provision could be guaranteed. The case study considered a hypothetical BCP at Nongan town Guoyuan village (44°44′685″ N, 125°08′03″ E) that was central to the straw collection area, and a centralized storage yard was adjacent to BCP. The selected BCP and its storage location have an existing railway and highway infrastructure, which might be a useful selection criterion to enable multi-model straw feedstock transportation in the future. The corn straw distribution was the same as the existing distribution of corn farmland, while the geographical distribution of the corn farmland was determined to use the land cover classification criterion proposed by Tang et al. (2018). Since the corn farmland distribution was located with high-resolution images from remote sensing technology, it did have the geographical coordinate as a parcel. The transportation distance between every corn farmland and BCP was calculated by using Baidu Maps (the major service provider for electronic navigation application in Mainland China).

The yield of corn in Nongan county was 6.9 tons/ha in 2018. Based on the straw-grain ratio and collectable coefficient (the conversion rate that measures the stubble height to impact the leftover straw), it could be measured that the theoretical maximum amount of corn straw was around 11 tons/ha. The agricultural machine data were taken from the National agricultural machinery testing and appraisal management service information platform (Agricultural machinery experiment and appraisal station, 2021) and Jilin agricultural machinery procurement subsidy information system (Jilin Agricultural Machine Management Bureau, 2021). The data for off-road forklifts were taken from the literature (Wei, 2014). It is assumed that this BCP in Nongan county required 200 thousand tons of corn straw.

The availability of straw feedstock has strong seasonal restrictions. The start day of straw collection cannot exceed the crop harvest day. According to the corn planting season in Northeast China, the harvest time for corn is in late September. The moisture of fresh corn straw after harvesting is high (>30%). So, the common practice is to let the corn straw expose in the farmland and wait for the water evaporation. Therefore, the work schedule of straw collection could be started from October. Straw supply chain is seriously affected by the weather conditions (temperature, rainfall etc.). Northeast China is located in the high latitude zone, and the temperature would be extremely low in the winter. Sokhansanj et al. (2006) suggested that, if the temperature is lower than -10 °C, that day should be considered as a non-work day for straw collection. Based on the local experience, the straw supply work should be completed before snowing (Ning, 2018). So, it would be terminated in early November, and it could be assumed that the time period for straw supply is 40 days. The time period for straw supply can be adjusted in accordance with the local needs or actual requirement from BCP.

4.2. Results and discussion

4.2.1. Baseline case analysis

Based on the statistical data in 2018, the results show that, 18,218 ha of corn farmland are necessary to produce 200 thousand tons of corn straw feedstock annually, which accounts for 5.4% of the total corn sowing area in Nongan county. The feedstock supply costs are 172 CNY/ton (See also Table. 2). Among the costs, baling-relating cost is the most significant cost, accounting for 49% of the total supply cost, followed by transportation (42.1%), loading (8.3%) and raking (0.6%); as for cost category, cost for energy consumption is the highest cost, accounting for 30.8% of the total supply cost, followed by cost of labor force recruitment (25%) and machine depreciation (22.7%). The other cost is the most minor cost category that, only took up 21.5% of the total supply cost. The results also show that the requirement of the machine was 9 hayrakes, 125 balers, 134 tractors, 53 forklifts and 406 trucks. The overall investment for machine procurement would be reached approximately 90 million CNY. The mean transportation distance is 14.5 km and using Euclidean distance without considering the realistic driving circumstance underestimates the transportation distance (8.2 km), so using electronic navigation applications (Baidu Maps, Google Maps, etc.) are the promising ways to promote the accuracy of cost calculation.

Fig. 13 compares straw feedstock supply cost from StrawFeed model with other similar studies from China. Instead of comparing the full supply chain with different research boundaries, the intersection of similar cost components is also extracted. The results indicate that, considering the geographical and temporal heterogeneity, the cost estimation from StrawFeed model is reasonable, and locates in the intermediate position among others. According to interviews with local brokers and BCP in Jilin province, and the reports by the media, the procurement price for straw feedstock by BCP is around 300 CNY/ton. After excluding the cost, the profit from straw feedstock supply chain could reach roughly 128 CNY/ton. For the implementer of straw feedstock supply chain, how to allocate this profit reasonably is a critical issue that should balance the interests of all stakeholders among investors, farmers and brokers themselves. This is an attempt by brokers to ensure sustainable and reliable straw feedstock supply in operation (See also Fig. 14).

(1) Broker to farmers: farmers could earn extra profit from selling straw

Table 2
The cost components (CNY/ton) of straw feedstock supply partitioned by activities (raking, baling, loading and transportation) in different scenarios.

Activities \ Scenarios	Baseline	Weather	Optimal	Hiring	Subsidy
Raking	1.0	1.1	1.8	0.8	0.9
Baling	84.3	92.9	84.3	66.9	75.7
Loading	14.3	15.4	14.3	12.2	14.3
Transportation	72.5	85.3	162.8	61.6	72.5
Supply Cost	172.0	194.6	263.2	141.5	163.4

Notes: The column "Baseline" represents baseline case, and "Weather", "Optimal", "Hiring", "Subsidy" represent scenario1–4 correspondingly.

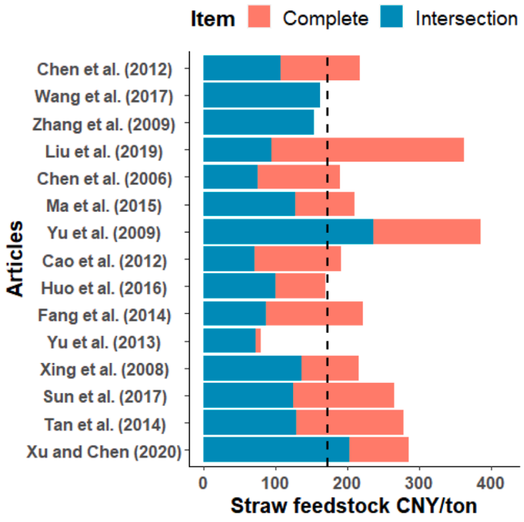

Fig. 13. The comparison of straw feedstock supply cost in China. The dashed line represents the estimated result from StrawFeed model (172 CNY/ton). The item 'Complete' stands for the overall supply cost contains cost component reported from articles respectively, and 'Intersection' stands for the common cost components between StrawFeed model and cited articles.

Even though farmers are willing to provide the straw feedstock complimentary in the early stage, due to the requirement from agricultural production, they are eager to share the profit as for long-term suppliers. Bioenergy production has economies of scale (Visser et al., 2020; Zhao et al., 2020; Aui et al., 2021). In other words, with the increase of production scale, the unit production cost could be cheaper by the relative reduction of unit variable capital investment. In addition, market distortion is induced by taxation preference and allowance policy favouring one single plant over another, expelling small size BCP by larger ones, thus benefiting from economy of scale. So, bioenergy investor prefers large-scale bioenergy production scheme. For example, the capital investment for a 50MW straw-based power plant in Jilin province could reach 553 million CNY (UNFCCC CDM, 2021a). However, large-scale production has high concerns about the sustainability of feedstock provision. The bargaining power of buyers (BCP) is weaker due to the non-replacement of local supplier (Zhao et al., 2016), and the feedstock provision entirely relies on local supply. The farmers may have risk to blackmail with egregious prices by taking the advantage of local monopoly position.

Under such circumstance, it is necessary to share the benefits with the farmers in return for their support. In this respect, straw-to-energy production projects and straw feedstock supply chain should also undertake the social responsibility of employment creation and income increase. During the straw feedstock supply period, there is a demand for recruitment of massive laborers, and it also would not compete with farmers' ordinary agricultural production because it occupies farmers' idle time. The results from StrawFeed model indicated that around 623 skilled farmers could be recruited, and the BCP would spend about 8.6 million CNY on labor recruitment, which accounts for 25% of straw feedstock supply cost. Selling straw feedstock could bring a new source of increasing household income by utilizing crop residues in agricultural production. According to the cost-benefit analysis of corn production in Jilin province, farmers could earn a net profit of 1301 CNY/ha (excluding rent). Assuming that the profit of straw feedstock supply could be partitioned among major entities equally, with the inclusion of selling straw feedstock, farmers could earn an extra profit of 504 CNY/ha (See also Fig. 15), where the income from agricultural production could raise about 39%. Therefore, instead of burning the straw as waste, selling it on the market for bioenergy production is a better solution (Palmieri et al., 2017). Hence, it could be observed that the development of bioenergy production and straw feedstock supply chain could also achieve social benefits.

(2) Broker to BCP: BCP could become potential stakeholder to provide monetary support

StrawFeed model also has the function of estimating the capital investment of straw feedstock supply chain. The results indicate that, the capital investment is about 90 million CNY. This figure is 18% of the investment of a typical straw-based power station in Nongan county (UNFCCC CDM, 2021b). Nguyen et al. (2016) proposed a similar estimation that, the investment of rice straw feedstock supply chain in the Mekong River delta of Vietnam represented 10–20% of the total investment of bioenergy production. Considering unfavorable factors in operation, the straw feedstock supply chain is fragile and risky, which makes it challenging to attract investors. The owned capital from brokers cannot satisfy the monetary requirement to some extent. In this case, the brokers should have long-term strategic consciousness, and how to benefit BCP from sharing profit. As for the consumers of straw feedstock, they also have a strong willingness to secure the sustainability and reliability of straw feedstock supply chain. BCP could become the potential benefactors and investors to provide monetary support, and become one of the major stakeholders in straw feedstock supply chain. If the profit is shared equally among entities, the procurement price from the broker can be reduced by around 14% (257 CNY/ton). With the reasonable profit allocation mechanism, it could be expected that a triple-win solution could be achieved among farmers, brokers and BCP.

Sensitivity and uncertainty analysis are practical tools to explore the robustness and reliability of StrawFeed model (Saba et al., 2020). They are helpful for identifying and quantifying the impacts and potential risks of business operation (Dimitriou et al., 2018). With respect to fuel

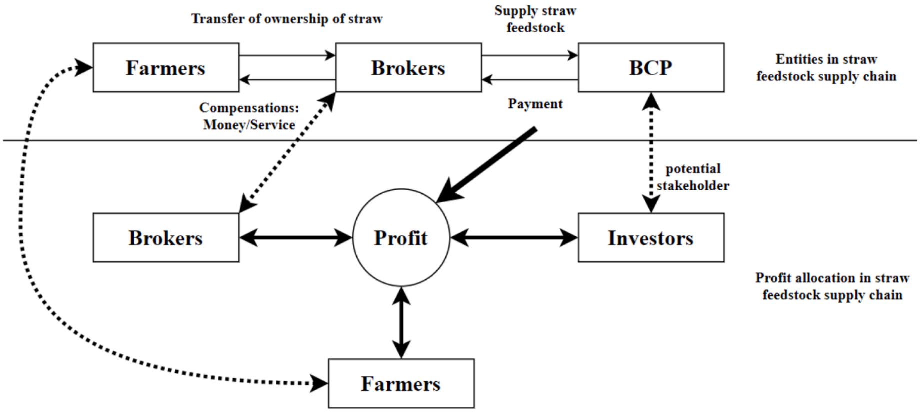

Fig. 14. The graphical illustration of major entities in straw feedstock supply chain, and the profit allocation among the major entities.

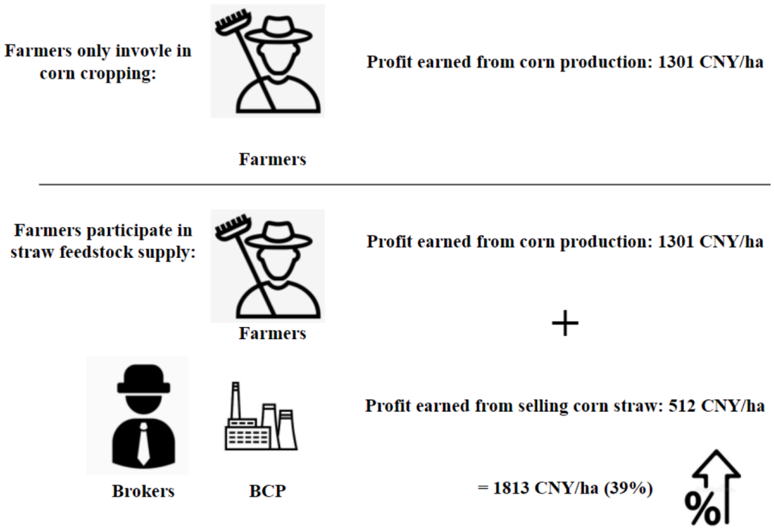

Fig. 15. The graphical illustration of the benefit of straw feedstock supply chain on farmers in Jilin province.

price, labor cost, idle time, speed (in transportation) and daily working hour are included in sensitivity and uncertainty analysis. The purpose is to identify the impacts of $a \pm 25\%$ change in these crucial parameters on overall straw feedstock supply cost. The result is shown in Table S1. Daily working hour is the greatest contributor to the variance in straw feedstock supply cost. This is because the increase or decrease can directly affect the number of machines used correspondingly. The second-largest contributor is the fuel price. With the promotion of mechanization, the diversity of fuel price can also bring about the fluctuation of straw feedstock supply cost. Furthermore, uncertainty analysis with Monte Carlo simulation is employed to concentrate on risk quantification (Dimitriou et al., 2018). Assuming that these uncertain parameters follow triangular distribution (Trivedi et al., 2015), and their lower and upper limits are set to be half and double of predefined values. Monte Carlo simulation runs 10, 100, 1000, and 10,000 times respectively to get confidence interval of straw feedstock supply cost. The result shows that, with the increase of iteration, the values converge and remain stable. It indicates that, the trend of these potential risks can be foreseen in advance, and these risks in business operation can be addressed effectively with proper management. The results from sensitivity and uncertainty analysis reveal that StrawFeed model is robust and reliable in modeling straw feedstock supply chain.

4.2.2. *The delayed work days caused by weather severely increase the straw supply cost*

The results from StrawFeed model showed that, supply cost almost increases 22.6 CNY per ton when the available working days are reduced by 25% (only 30 working days are available). In other words, reducing the number of supply days by 25% resulted in an increase in the estimated cost of delivering straw feedstock by 13%. This is because in the case of fewer working days, more collection machines and trucks are required to complete the feedstock collection and transportation tasks. Similarly, Mapemba et al. (2008) found that harvest costs almost double when the available harvest days are reduced by 50% in delivering biomass feedstock in Oklahoma, US. Furthermore, extreme weather will bring more devastating repercussions. If the crop production is destroyed by extreme weather, it could lead to a total crop failure and impair the stable straw feedstock supply (“everything goes wrong”, Junginger et al. (2001)). For instance, Northeast China used to experience severe agricultural meteorological disasters, the area of total crop failure could reach 33% of the crop sowing area (Wang et al., 2001 He et al., 2019). The work of straw supply may come to a standstill for the absence of straw feedstock. Such a situation should also be incorporated into enterprise risk-based inspection.

Hence, how to manage the risks from weather uncertainty is crucial for the sustainable and stable operation of straw feedstock supply and bioenergy production. The corresponding suggestions are proposed as follows: (1) Weather is an important criterion for BCP site selection. The low rainfall and snow amount in the supply area could increase the likelihood of successfully collecting and transporting straw feedstock from crops. (2) The accurate weather forecasting is indispensable for BCP. Based on the historical and forecasting weather data, BCP should establish a weather-working days coupling evaluation mechanism to appraise the requirements of the machine before executing straw collection works. When the weather could be foreseen to be unfavorable for straw supply, the BCP should arrange the proper number of machines dynamically, and make sure that the demanded amount of straw should be supplied on time. (3) Agricultural production management decisions. Combined with crop calendars and precipitation records, the crop growing season could be analyzed via crop growth models (APSIM, DSSAT, etc.). With the help of these models, the crop harvesting season could be predicted in advance, and the appropriate straw harvesting schedule could be designed in accordance with weather forecasting. Furthermore, in assistance with local government and agricultural organizations, the grant arrangement of harvest time varieties in a specific region should also consider the request from straw feedstock supply. The diversification strategy of harvest time varieties could avoid the intensified straw harvesting activity. The accomplishments of these works require cooperation with agronomic experts, and it is a good opportunity to strengthen the connection between agricultural and bioenergy production.

4.2.3. *Lower amount of straw removed from farmland, the straw supply cost would be higher*

The amount of straw that could be removed from field is significantly lower than full straw removal, and the change of available coefficient (amount of straw removal) that would impact the straw supply cost is largely unknown. The results of StrawFeed model reveal that, decreasing availability coefficient could bring longer collectable radius and mean transportation distance, and thereby fuel consumption and vehicle requirement would raise simultaneously (See also Fig. 16). The unit cost of straw supply in half amount of straw removal is 53% higher than the baseline scenario (full straw removal). In other words, an optimal scheme of straw comprehensive utilization (the requirement of straw for soil nutrient or competition use) could achieve environmental and ecological benefits for the public and farmers, but it has a risk to damage the profitability of BCP. However, if straw feedstock is entirely removed without returning to farmland, it could cause the depletion of soil

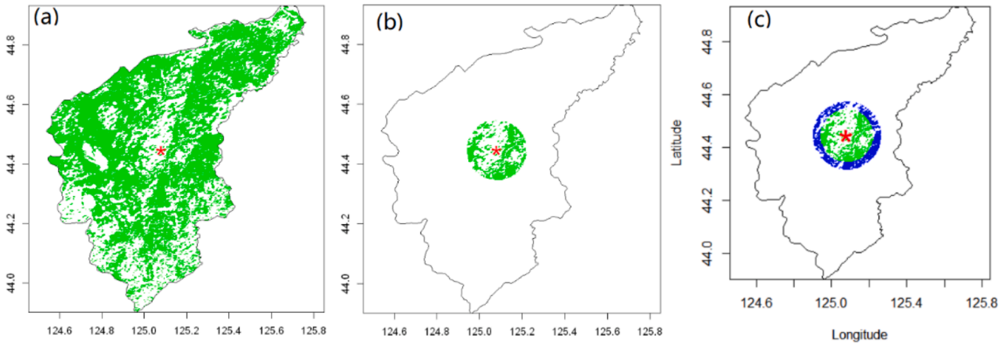

Fig. 16. (a) The distribution of corn cropping area in Nongan county; (b) the straw feedstock collectable area for BCP in baseline case; (c) the straw feedstock collectable area for BCP in optimal straw utilization scenarios. The green color in (b) and (c) represents the mean transportation distance is below 14.5 kms, and blue color in (c) represents the collectable radius is greater than 14.5 kms but lower than 18 kms.

nutrient. Straw return to farmland has a great potential to reduce the use of chemical fertilizers (Yin et al., 2018). It is reported that, full corn straw return in Northeast China could counterbalance 38.2% of N, 30.9% of P_2O_5, and all of K_2O in chemical fertilizers (Song et al., 2018). Based on the usage of chemical fertilizer from Ministry of Agriculture (2013) and the cost of chemical fertilizer from National Development and Reform Commission (2021), it could be further estimated that, theoretically farmer should pay for a maximum of 1055 RMB per ha for maintaining constant soil fertility, under the circumstance of full straw removal. On the other hand, the cost of straw return (1350 per ha in Northeast China, Wang et al. (2021b)) usually exceeds its benefit from soil nutrients, and these factors influence farmer's decision-making on straw utilization.

Profit maximization is the only concern for BCP, and if merely considering the profit in straw supply chain, full straw removal is the cheapest way. So, there would be a conflict of balancing the benefits of companies' operation and the environment. In the future, it is suggested that straw utilization should be integrated into a comprehensive framework, including straw retention and straw removal for other proposes. The 3E (Economy, Environment, and Ecology) evaluation is required to provide the contingent value of different straw utilization modes in the future. Not only monetary return is estimated, but also ecoefficiency ratio should be concerned, from the perspective of achieving greater economic value with lower environmental impacts (Palmieri et al., 2020). With the participation of BCP (optimal amount of straw removal from farmland), the comprehensive 3E benefits could be better than single straw utilization modes (straw open burning, full straw retention, full straw removal).

The lower the amount of straw feedstock could be supplied from farmland, the larger the straw feedstock collectable area, and accordingly the higher the raking and transportation-related costs. Therefore, more straw utilization options could reduce the potential risk of straw open burning, but require higher straw feedstock supply cost. Balancing the trade-off between raking and transportation costs and the benefit of comprehensive straw utilization would be important for an efficient design of straw feedstock supply chain. The results obtained from 3E evaluation could support BCP to apply for circular economy projects, so as to seek more funds to compensate for the increased operational cost. Another possible expected way is the upturn of carbon market. Apart from conventional CDM to trade carbon credit from bioenergy production, the optimization from straw feedstock supply chain could earn more carbon abatement. Kongchouy et al. (2021) explored that, if the proportion of straw feedstock removed could raise from 50% (baseline case) to 75%, the estimated greenhouse gas emission could reduce about 1.5 times greater than the baseline case, and such reduction could bring higher revenue for bioenergy producers, if the quota of abatement could be traded in the carbon market.

4.2.4. *Hiring is cheaper than buying machines*

To estimate the depreciation of machines under hiring circumstance, the units-of-production depreciation method (the actual usage hour) is used instead. The unit straw supply cost could be saved by 18% when machines are hired during straw supply period. The findings from the modeling support that, cross-regional operation of agricultural machine, could not only reduce the cost of agricultural machinery service acquisition (Huang and Luo, 2020), but also reduce the cost of straw supply, which is seldom mentioned or discussed in previous studies.

While giant state-owned energy companies might afford to equip with all the necessary machines, there is a need to find technological and institutional solutions to enable mechanization for private enterprises and brokers, who play a crucial role in straw-based bioenergy development. Without such options, the high amount of investment for machine procurement would bring heavy financial burden on the stable operation of straw feedstock supply. The transaction cost in the machine hiring market should be noticed. The results from StrawFeed model do not consider the transaction cost, because it is uneasy to estimate. Coase (1937) argued that the cost of acquiring service through the market is more than just the price of service itself. Other costs, including search and information costs, as well as negotiation costs, should be added to the cost of purchasing something with a market. The information asymmetry existed between farmers and owners of agricultural machines. The time of harvesting is short and precious, but neither farmers nor owners had effective apparatus to contact each other (Zhang et al., 2018, 2020). In view of information asymmetry, the convenience of the development of communication via Internet could reduce the transaction cost significantly. In developing countries like India and Nigeria, the popularization of digital tools ("Uber for tractors" model) could reduce transaction costs for service providers and enable farmers to access tractor hire services (Daum et al., 2021). In China, the construction of cloud platform encourages application design. With the development of mobile applications and agricultural machinery intelligent acquisition terminals, the supply and demand of agricultural machines could be connected (Zhang et al., 2020).

4.2.5. *To pursue subsidy in agricultural machine procurement could reduce the cost*

Taking the advantage of farmers' identity from brokers, buying balers and tractors could be cheaper. The subsidies for hayrakes, balers and tractors (for dragging hayrakes and balers) are 4800, 40,190, 15,410, 96,430 respectively, which is estimated the financial saving could reach 8.6 CNY/ton (5% reduction). Hence, this is another advantage of selecting broker acquisition mode instead of self-acquisition in China, which has rarely been mentioned and discussed in previous studies. Straw feedstock supply chain is not a winner-take-all system, and it is important to learn how to cooperate with other partners, thereby maximizing the benefit with comparative advantage.

4.2.6. The integration of strawfeed model with techno-economic models

StrawFeed model is flexible and adaptable for integrating with existing techno-economic models. It provides a cradle-to-gate solution on straw feedstock supply, where techno-economic modes have better performance and higher accuracy on filling the knowledge gap in bioenergy production stage. Many researchers have established techno-economic models to assess straw-based bioenergy products, such as electricity in Egypt (Abdelhady et al., 2018), Bolivia (Morato et al., 2020), and bioethanol in Japan (Roy et al., 2012b), Sweden (Ljunggren et al., 2011), Brazil (Pratto et al., 2020) and Malaysia (Kristianto et al., 2017). Apart from technical or chemical concerns, the feedstock supply chain also has a strong influence on the eventual outcome. StrawFeed model can be assembled as a submodel to be integrated with other techno-economic models, and it can be useful for providing sound results in feedstock supply chain, or checking the reliability of existing results. Better still, the integration of StrawFeed model can benefit techno-economic model to clarify geographical difference to some extent, and thus making the results more comparable.

5. Conclusion

This paper presents a comprehensive solution tool, StrawFeed model, to overcome the challenges of straw feedstock supply chain planning, which is beneficial for both academic research and commercial bioenergy projects. The unique feature of this model is the integration of remote sensing technology as well as electronic navigation application by using an open-source programming platform. A case study of corn straw supply in Nongan county, Northeast China is applied. The results illustrate that the unit cost of corn straw supply was 172 CNY/ton, to deliver 200 thousand tons for energy purpose. Considering the realistic circumstances of agricultural production and bioenergy production, as well as policy intervention in China, two potential obstacles and two improvements in straw feedstock supply are discussed in accordance with four contrived scenarios. Weather (rain and snow, etc.) would shorten the available working period, thus increasing the supply cost remarkably. An optimal straw utilization scheme could achieve environmental and ecological benefits, and is favoured by the public and government, but it also increases the supply cost by prolonging collection radius. The extra expenses burdened by BCP is neglected by previous research. Due to the seasonal availability and restricted working period of straw feedstock, hiring machines are cheaper than owning machines, when the cross-regional machine operation could be fully achieved. On the contrary, if BCP is apprehensive about the competition for hiring services, instead of purchasing the machines by themselves, it is suggested to cooperate with brokers to grasp the proprietary machine-purchasing subsidy for farmers. The scenario analysis and optimization provide enlightenment for future research directions. The experiences and lessons learned from straw feedstock supply chain in China could enlighten countries around the world and inspire their individual practice and management, which is especially applicable for developing countries facing similar circumstances with China.

CRediT authorship contribution statement

Shu Wang: Conceptualization, Data curation, Formal analysis, Methodology, Software, Visualization, Writing – original draft. **Changbin Yin:** Funding acquisition, Supervision, Validation, Writing – review & editing. **Jian Jiao:** Project administration, Writing – review & editing. **Xiaomei Yang:** Project administration, Writing – review & editing. **Boyang Shi:** Project administration, Writing – review & editing. **Aurore Richel:** Project administration, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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References

Abdelhady, S., Borello, D., Shaban, A., 2018. Techno-economic assessment of biomass power plant fed with rice straw: sensitivity and parametric analysis of the performance and the LCOE. Renew. Energ. 115, 1026–1034.

Agricultural machinery experiment and appraisal station, 2021. National agricultural machinery testing and appraisal management service information platform URL: http://202.127.42.49:8080/nongji/front/main/serach.do (Accessed 17 March 2022).

Ahamed, T., Tian, L., Zhang, Y., Ting, K., 2011. A review of remote sensing methods for biomass feedstock production. Biomass Bioenerg. 35, 2455–2469.

Allen, J., Browne, M., Hunter, A., Boyd, J., Palmer, H., 1998. Logistics management and costs of biomass fuel supply. Int. J. Phys. Distrib. Logist. Manag. 28, 463–477.

Aui, A., Wang, Y., Mba-Wright, M., 2021. Evaluating the economic feasibility of cellulosic ethanol: a meta-analysis of techno-economic analysis studies. Renew. Sust. Energ. Rev. 145, 111098.

Aguiar, A., Milessi, T.S., Mulinari, D.R., Lopes, M.S., da Costa, S.M., Candido, R.G, 2021. Sugarcane straw as a potential second generation feedstock for biorefinery and white biotechnology applications. Biomass Bioenerg 144, 105896.

Banowetz, G.M., Boateng, A., Steiner, J.J., Griffith, S.M., Sethi, V., El-Nashaar, H., 2008. Assessment of straw biomass feedstock resources in the Pacific Northwest. Biomass Bioenerg. 32, 629–634.

BASIS, 2015. Report on conversion efficiency of biomass.

Beijixing, 2019. Nearly 100 biomass power generation projects are planned in Jilin Province. https://huanbao.bjx.com.cn/news/20191225/1031493.shtml (Accessed 8 June 2022).

Bhutto, A.W., Qureshi, K., Harijan, K., Abro, R., Abbas, T., Bazmi, A.A., Karim, S., Yu, G., 2017. Insight into progress in pre-treatment of lignocellulosic biomass. Energy 122, 724–745.

Biomass Energy Resource Center, 2009. Biomass energy: efficiency, scale, and sustainability.

Borjesson, P., Gustavsson, L., 1996. Regional production and utilization of biomass in Sweden. Energy 21, 747–764.

Calvert, K., 2011. Geomatics and bioenergy feasibility assessments: taking stock and looking forward. Renew. Sust. Energ. Rev. 15, 1117–1124.

Cao, J., Pang, B., Mo, X., Xu, F., 2016. A new model that using transfer stations for straw collection and transportation in the rural areas of China: a case of Jinghai. Tianjin. Renew. Energ. 99, 911–918.

Cao, Y., Shen, H., 2012. A research on collection cost in the process of straw power generation. Power Energ. 33, 463–466 (In Chinese).

CAAMM (China Association of Agricultural Machinery Manufacturers), 2012-2019. China Agricultural Machinery Industry Yearbook 2012-2019, China Machine Press, Beijing, China.

Chen, L., Xu, Z., Zhang, G., Zhao, B., Zhu, C., 2006. A small-scale biomass combustion generation project and its benefit analysis. Water Conserv. Electr. Power Mach. (In Chinese) 28, 1–4.

Chen, L., Li, Y., Ding, W., Liu, J., Shen, B., 2012. Analysis on straw logistics cost of direct-fired power generation using activity-based costing. Trans. CSAE (In Chinese) 28, 199203.

Chinese Agriculture Outlook Committee, 2021. Chinese agricultural supply and demand estimates. URL: http://www.agri.cn/V20/SC/gxxs/202104/P020210409498094441795.pdf (Accessed 17 March 2022).

Chiu, Y.C., Guo, S.J., Chen, S., Tsai, C., Tsai, J.M., 2016. Planning the collection and transportation of rice straw in Nantou County. Taiwan. Appl. Eng. Agric. 32, 531–538.

Coase, R., 1937. The nature of the firm. Economica 4, 386–405.

Cundiff, J.S., Dias, N., Sherali, H.D., 1997. A linear programming approach for designing a herbaceous biomass delivery system. Bioresource Technol. 59, 47–55.

Daum, T., Villalba, R., Anidi, O., Mayienga, S.M., Gupta, S., Birner, R., 2021. Uber for tractors? Opportunities and challenges of digital tools for tractor hire in India and Nigeria. World Dev. 144, 105480.

Delivand, M.K., Barz, M., Gheewala, S.H., 2011. Logistics cost analysis of rice straw for biomass power generation in Thailand. Energy 36, 1435–1441.

Dimitriou, L., Goldingay, H., Bridgwater, A., 2018. Techno-economic and uncertainty analysis of Biomass to Liquid (BTL) systems for transport fuel production. Renew. Sust. Energ. Rev. 88, 160–175.

Engard, N.C., 2010. What is Open source? Practical Open Source Software For Libraries. Chandos Publishing, pp. 3–11.

Fang, Y., Shuhua, L., Linfeng, W., Lantian, R., Guanghui, X., 2014. Model establishment and cost analysis on wheat straw logistic system. J. China Agri. Univ. (In Chinese) 19, 28–35.

Feng, J., He, K., Zhang, J., 2014. Family endowments constrain farmer demand for energy utilization of crop straws. Resour. Sci. (In Chinese) 36, 530–537.

Friedlingstein, P., M, O., Jones, M.W., M, A.R., S, Z., 2020. Global carbon budget 2020. Earth Syst. Sci. Data 12, 3269–3340.

Garcia, R., Freire, F., 2014. Carbon footprint of particleboard: a comparison between ISO/TS 14067, GHG Protocol, PAS 2050 and climate declaration. J. Clean. Prod. 66, 199–209.

Gosens, J., 2015. Biopower from direct firing of crop and forestry residues in China: a review of developments and investment outlook. Biomass Bioenerg. 73, 110–123.

He, G., Liu, T., Zhou, M., 2020. Straw burning, pm2.5, and death: evidence from China. J. Dev. Econ. 145, 102468.

He, X., Xiao, L., Hong, Y., Songcai, Y., 2019. Characteristics of major agricultural meteorological disasters in Northeast China from 1986 to 2015. J. Shenyang Agri. Univ. (In Chinese) 50, 392–398.

Hess, J.R., Wright, C.T., Kenney, K.L., 2007. Cellulosic biomass feedstocks and logistics for ethanol production. Biofuels Bioprod. Biorefining 1, 181–190.

Yu, H., Wang, Q., Klein, E., Yu, C., Luo, Z., Cen, K., 2010. Optimization and analysis of bio-fuel logistics for biomass power plant. Trans. CSAE 26, 293–297.

Huang, W., Huang, H., Zhu, W., 2012. An empirical study on farmer's utilization of crop straw. China Rural Survey (In Chinese) 106, 37–43, 69.

Huang, X., Cheng, L., Chien, H., Jiang, H., Yang, X., Yin, C., 2019. Sustainability of returning wheat straw to field in Hebei, Shandong and Jiangsu provinces: a contingent valuation method. J. Clean. Prod. 213, 1290–1298.

Huang, Y., Luo, X., 2020. How does cross-regional operation affect agricultural machinery service acquisition? J Huazhong Agri. Univ. (Social Science Edition, In Chinese) 148, 89–97.

Huo, L., Wu, J., Zhao, L., Yao, Z., Hou, S., 2016. Establishment and application of crops straw supply model for north China plain area. Trans. CSAE (In Chinese) 32, 106–108.

Ishii, K., Furuichi, T., Fujiyama, A., Watanabe, S., 2016. Logistics cost analysis of rice straw pellets for feasible production capacity and spatial scale in heat utilization systems: a case study in Nanporo town, Hokkaido, Japan. Biomass Bioener. 94, 155–166.

Jiang, L., Xue, B., Ma, Z., Yu, L., Huang, B., Chen, X., 2020. A life-cycle based co-benefits analysis of biomass pellet production in China. Renew. Energ. 154, 445–452.

Jilin Agricultural Machine Management Bureau, 2021. Jilin agricultural machinery purchase subsidy information system. URL: http://njbt.jlnongji.cn/ (Accessed 17 March 2022).

Junginger, M., Faaij, A., van den Broek, R., Koopmans, A., Hulscher, W., 2001. Fuel supply strategies for large-scale bio-energy projects in developing countries. Electricity generation from agricultural and forest residues in Northeastern Thailand. Biomass Bioenerg. 21, 259–275.

Kadam, K.L., Forrest, L.H., Jacobson, W., 2000. Rice straw as a lignocellulosic resource: collection, processing, transportation, and environmental aspects. Biomass Bioenerg. 18, 369–389.

Kaiser, M.J., 2019. The role of factor and activity-based models in offshore operating cost estimation. J. Petrol. Sci. Eng. 174, 1062–1092.

Kaylen, M., Dyne, D.L.V., Choi, Y.S., Blase, M., 2000. Economic feasibility of producing ethanol from lignocellulosic feedstocks. Bioresource Technol. 72, 19–32.

Ko, S., Lautala, P., Handler, R.M., 2018. Securing the feedstock procurement for bioenergy products: a literature review on the biomass transportation and logistics. J. Clean. Prod. 200, 205–218.

Kristianto, Y., Zhu, L., 2017. Techno-economic optimization of ethanol synthesis from rice-straw supply chains. Energy 141, 2164–2176.

Kongchouy, P., W, T., et al., 2021. Assessment of seasonal availability and spatial distribution of bio-feedstock for power generation in Thailand. Bioenerg. Res. 14, 70–90.

Korpunen, H., Raiko, R., 2014. Testing activity-based costing to large-scale combined heat and power plant using bioenergy. Int. J. Energy Res. 38, 339–349.

Kuang, E., Chi, F., Jeng, A.S., Su, Q., Zhang, J., 2014. A comparison of different methods of decomposing maize straw in China. Acta. Agr. Scand. B-S P 63, 186–194.

Kuisma, M., Kahiluoto, H., Havukainen, J., Lehtonen, E., Luoranen, M., Myllymaa, T., Grönroos, J., Horttanainen, M., 2013. Understanding biorefining efficiency – The case of agrifood waste. Bioresource Technol. 135, 588–597.

Kumar, A., Sokhansanj, S., 2007. Switchgrass (Panicum vigratum, L.) delivery to a biorefinery using integrated biomass supply analysis and logistics (IBSAL) model. Bioresource Technol. 98, 1033–1044.

Laasasenaho, K., Lensu, A., Lauhanen, R., Rintala, J., 2019. GIS-data related route optimization, hierarchical clustering, location optimization, and kernel density methods are useful for promoting distributed bioenergy plant planning in rural areas. Sustain. Energy Techn. 32, 47–57.

Latterini, F., Stefanoni, W., Suardi, A., Alfano, V., Bergonzoli, S., Palmieri, N., Pari, L., 2020. A GIS approach to locate a small size biomass plant powered by olive pruning and to estimate supply chain costs. Energies 13, 3385.

Leboreiro, J., Hilaly, A.K., 2011. Biomass transportation model and optimum plant size for the production of ethanol. Bioresource Technol. 102, 2712–2723.

Li, H., Dai, M., Dai, S., Dong, X., 2018. Current status and environment impact of direct straw return in China's cropland – a review. Ecotox. Environ. Safe. 159, 293–300.

Lin, T., LF, R., YN, S., AC, H., Ting, K., 2013. GIS-enabled biomass-ethanol supply chain optimization: model development and Miscanthus application. Biofuels, Bioprod. Bioref. 7, 314–333.

Liska, A., Yang, H., Milner, M., Goddard, S., Canqui, H., Pelton, M., Fang, X., Zhu, H., Suyer, A., 2014. Biofuels from crop residue can reduce soil carbon and increase CO_2 emissions. Nature Clim. Change 4, 398–401.

Littlewood, J., Murphy, R., Wang, L., 2013. Importance of policy support and feedstock prices on economic feasibility of bioethanol production from wheat straw in the UK. Renew. Sust. Energ. Rev. 17, 291–300.

Liu, B., Wu, Q., Wang, F., 2017. Regional optimization of new straw power plants with greenhouse gas emissions reduction goals: a comparison of different logistics modes. J. Clean. Prod. 161, 871–880.

Liu, D., Rile, S., Xiangnin, S., Xiaoni, Z., 2019. Selection of straw collection and storage model based on factors of rate of collecting and storage: taking typical area of Guanzhong as an example. Modern Agri. Sci. Technol. (In Chinese) 36, 154–158.

Liu, Z., David, F., 2014. Soil function-included simulation on energy development potential of corn stover. Trans. CSAE (In Chinese) 30, 236–243.

Ljunggren, M., Wallberg, O., Zacchi, G., 2011. Techno-economic comparison of a biological hydrogen process and a 2nd generation ethanol process using barley straw as feedstock. Bioresour. Technol. 102, 9524–9531.

Long, Z., Zhang, Z., Liang, S., Chen, X., Ding, B., Wang, B., Chen, Y., Sun, Y., Li, S., Yang, T., 2021. Spatially explicit carbon emissions at the county scale. Resour. Conserv. Recy. 173, 105706.

Lovrak, A., Puksec, T., Duic, N., 2020. A Geographical Information System (GIS) based approach for assessing the spatial distribution and seasonal variation of biogas production potential from agricultural residues and municipal biowaste. Appl. Energ. 267, 115010.

Ma, F., Zhang, X., Wang, L., 2015. Economic and environmental evaluation of straw transportation radius for straw-energy engineering. J. Harbin Inst. Technol. (In Chinese) 47, 48–53.

MacLean, H.L., Lave, L.B., 2003. Evaluating automobile fuel/propulsion system technologies. Prog. Energy Combust. Sci. 29, 1–69.

Mapemba, L.D., Epplin, F.M., Huhnke, R.L., Taliaferro, C.M., 2008. Herbaceous plant biomass harvest and delivery cost with harvest segmented by month and number of harvest machines endogenously determined. Biomass Bioenerg. 32, 1016–1027.

Menandro, L., de Moraes, L.O., et al., 2019. Soil Macrofauna responses to sugarcane straw removal for bioenergy production. Bioenerg. Res. 12, 944–957.

Ministry of Agriculture, 2013. Regional formula and fertilization recommendations for the three major food crops, wheat, corn and rice (2013). http://www.moa.gov.cn/nybgb/2013/dbaq/201712/t20171219_6119839.htm (Accessed 17 March 2022).

Ministry of Agricultural and Rural Affairs, 2019. 2018-2020 National Agricultural Machinery Purchase Subsidy Machine Type Range. URL: http://www.moa.gov.cn/nybgb/2018/201803/201805/t20180528_6143198.htm (Accessed 17 March 2022).

Ministry of Agricultural and Rural Affairs, 2021. Implementation opinions on the deployment of key agricultural and rural work in 2021 URL: http://www.moa.gov.cn/govpublic/FZJHS/202102/t20210225_6362310.htm (Accessed 17 March 2022).

Ministry of Transport, 2020. Notice of reservation for expressway vehicle toll discount URL: http://www.gov.cn/zhengce/zhengceku/2020-06/24/content_5521537.htm (Accessed 17 March 2022).

Mol, R., Jogems, M., Beek, P., Gigler, J., 1997. Simulation and optimization of the logistics of biomass fuel collection. Neth. J. Agri. Sci. 45, 219–228.

Morato, T., Vaezi, M., Kumar, A., 2020. Techno-economic assessment of biomass combustion technologies to generate electricity in South America: a case study for Bolivia. Renew. Sust. Energ. Rev. 134, 110154.

Natarajan, K., Latva-Käyrä, P., Zyadin, A., Pelkonen, P., 2016. New methodological approach for biomass resource assessment in India using GIS application and land use/land cover (LULC) maps. Renew. Sust. Energ. Rev. 63, 256–268.

National Development and Reform Commission, 2021. Compilation of Cost-Benefit Data of National Agricultural products-2021. Statistical Publishing House, Beijing, China.

National Energy Administration, 2016. The Graphical Illustration of "13th Five-Year-Plan of Biomass Energy Development. National Energy Administration. URL. http://www.nea.gov.cn/2016-12/14/c_135904504.htm (Accessed 17 March 2022).

National People's Congress, 2005. Interpretation of the Agricultural Mechanization Promotion Law of the People's Republic of China URL: http://www.npc.gov.cn/npc/c2191/flsyywd_list.shtml (Accessed 17 March 2022).

Nguyen, T., Hermansen, J., Mogensen, L., 2013. Environmental performance of crop residues as an energy source for electricity production: the case of wheat straw in Denmark. Appl. Energ. 104, 633–641.

Nguyen, H.V., Nguyen, C.D., Tran, T.V., Hau, H.D., Nguyen, N.T., Gummert, M., 2016. Energy efficiency, greenhouse gas emissions, and cost of rice straw collection in the mekong river delta of Vietnam. Field Crop Res. 198, 16–22.

Nilsson, D., 1999. SHAM—A simulation model for designing straw fuel delivery systems. Part 1: model description. Biomass Bioenerg. 16, 25–38.

Ning, K., 2018. Research on straw-to-energy utilization strategy in Heilongjiang province. Farm Econ. Manage. (In Chinese) 25, 31–34.

Niu, W., Han, L., Liu, X., Huang, G., Chen, L., Xiao, W., Yang, Z., 2016. Twenty-two compositional characterizations and theoretical energy potentials of extensively diversified China's crop residues. Energy 100, 238–250.

Oh, S.C., Hildreth, A., 2013. Decisions on energy demand response option contracts in smart grids based on activity-based costing and stochastic programming. Energies 6, 425–443.

Open Source Initiative, 2020. GNU General Public License version 3 URL: https://opensource.org/licenses/gpl-3.0.html (Accessed 17 March 2022).

Palmieri, N., Forleo, B., Giannoccaro, G., Suardi, A., 2017. Environmental impact of cereal straw management: an on-farm assessment. J. Clean. Prod. 142, 2950–2964.

Palmieri, N., Suardi, A., Alfano, V., Pari, L., 2020. Circular economy model: insights from a case study in south Italy. Sustainability 12, 3466.

Panichelli, L., Gnansounou, E., 2008. GIS-based approach for defining bioenergy facilities location: a case study in Northern Spain based on marginal delivery costs and resources competition between facilities. Biomass Bioenerg. 32, 289–300.

Pratto, B., Sabtos, S., Longati, A., Sousa, R., Cruz, A., 2020. Experimental optimization and techno-economic analysis of bioethanol production by simultaneous saccharification and fermentation process using sugarcane straw. Bioresour. Technol. 297, 122494.

Proietti, S., Desideri, U., Sdringola, P., Zepparelli, F., 2013. Carbon footprint of a reflective foil and comparison with other solutions for thermal insulation in building envelope. Appl. Energ. 112, 843–855.

Qin, Z., Zhai, G., Wu, X., Yu, Y., Zhang, Z., 2016. Carbon footprint evaluation of coal-to-methanol chain with the hierarchical attribution management and life cycle assessment. Energ. Convers. Manage. 124, 168–179.

Ren, J., Yu, P., Xu, X., 2019. Straw utilization in China—Status and recommendations. Sustainability 11, 1762.

Ren, W., Wu, K., Gu, Q., Hu, Y., 2020. Intelligent decision making for service providers selection in maintenance service network: an adaptive fuzzy-neuro approach. Knowl. Based Syst. 190, 105263.

Rentizelas, A., Tatsiopoulos, I., Tolis, A., 2009a. An optimization model for multi-biomass tri-generation energy supply. Biomass Bioener. 33, 223–233.

Rentizelas, A., Tolis, A.J., Tatsiopoulos, I.P., 2009b. Logistics issues of biomass: the storage problem and the multi-biomass supply chain. Renew. Sust. Energ. Rev. 13, 887–894.

Roy, P., Orikasa, T., Tokuyasu, K., Nakamura, N., Shiina, T., 2012a. Evaluation of the life cycle of bioethanol produced from rice straws. Bioresour. Technol. 110, 239–244.

Roy, P., Tokuyasu, K., Orikasa, T., Nakamura, N., Shiina, T., 2012b. A techno-economic and environmental evaluation of the life cycle of bioethanol produced from rice straw by RT-CaCCO process. Biomass Bioenerg. 37, 188–195.

Saba, S., Bachawati, M., Malek, M., 2020. Cradle to grave Life Cycle Assessment of Lebanese biomass briquettes. J. Clean. Prod. 253, 119851.

Said, N., Alblawi, A., Hendy, I., Daiem, M., 2020. Analysis of energy and greenhouse gas emissions of rice straw to energy chain in Egypt. BioRes 15, 1510–1520.

Shafie, S., Masjuki, H., Mahlia, T., 2014. Life cycle assessment of rice straw-based power generation in Malaysia. Energy 70, 401–410.

Sharifzadeh, M., Garcia, M.C., Shah, N., 2015. Supply chain network design and operation: systematic decision-making for centralized, distributed, and mobile biofuel production using mixed integer linear programming (MILP) under uncertainty. Biomass Bioenerg. 81, 401–414.

Sheehan, J., Aden, A., Paustian, K., Killian, K., Brenner, J., Wlash, M., Nelson, R., 2003. Energy and environmental aspects of using corn stover for fuel ethanol. J Ind. Ecol. 7, 117–146.

Soam, S., Borjesson, P., Sharma, P.K., Gupta, R.P., Tuli, D.K., Kumar, R., 2017. Life cycle assessment of rice straw utilization practices in India. Bioresource Technol. 228, 89–98.

Soimakallio, S., Kiviluoma, J., Saikku, L., 2011. The complexity and challenges of determining GHG (greenhouse gas) emissions from grid electricity consumption and conservation in LCA (life cycle assessment)- A methodological review. Energy 36, 6705–6713.

Sokhansanj, S., Kumar, A., Turhollow, A.F., 2006. Development and implementation of integrated biomass supply analysis and logistics model (IBSAL). Biomass Bioenerg. 30, 838–847.

Song, D., Hou, S., Wang, X., Liang, G., Zhou, W., 2018. Nutrient resource quantity of crop straw and its potential of substituting. J. Plant Nutr. Fertilizer. 24, 1–21.

Song, S., Liu, P., Xu, J., Chong, C., Huang, X., Ma, L., Li, Z., Ni, W., 2017. Life cycle assessment and economic evaluation of pellet fuel from corn straw in China: a case study in Jilin Province. Energy 130, 373–381.

Statistic Bureau of Jilin, 2019. Jilin Statistical Yearbook 2019. Statistical Publishing House, Beijing, China.

Suh, K., Suh, S., Walseth, B., Bae, J., Barker, R., 2011. Optimal corn stover logistics for biofuel production: a case in Minnesota. Trans. ASABE 54, 229–238.

Sultana, A., Kumar, A., 2014. Development of tortuosity factor for assessment of lignocellulosic biomass delivery cost to a biorefinery. Appl. Energ. 119, 288–295.

Sun, Y., Cai, W., Chen, B., Guo, X., Hu, J., Jiao, Y., 2017. Economic analysis of fuel collection, storage, and transportation in straw power generation in China. Energy 132, 194–203.

Tan, Q., Yang, H., Zhang, X., Deng, Y., Wei, Y., 2014. Measurement model and empirical analysis of fuel collection cost for biomass power generation. Forum Sci. Technol. China (In Chinese) 30, 117–123.

Tang, K., Zhu, W., Zhan, P., Ding, S., 2018. An identification method for spring maize in Northeast China based on spectral and phenological features. Remote Sens. (Basel) 10, 193.

Talebnia, F., Karakashev, D., Angelidaki, I., 2010. Production of bioethanol from wheat straw: an overview on pretreatment, hydrolysis and fermentation. Bioresour. Technol. 101, 4744–4753.

Tinoco, D., Genier, H.L.A., da Silveira, W.B., 2021. Technology valuation of cellulosic ethanol production by Kluyveromyces marxianus CCT 7735 from sweet sorghum bagasse at elevated temperatures. Renew. Energ. 173, 188–196.

Trivedi, P., Malina, R., Barrett, S., 2015. Environmental and economic tradeoffs of using corn stover for liquid fuels and power production. Energy Environ. Sci. 8, 1428.

UNFCCC CDM, 2021a. Project 7324: jiaohe Kaidi Biomass Power Project URL: https://cdm.unfccc.int/Projects/DB/CEC1347946234.69/view (Accessed 17 March 2022).

UNFCCC CDM, 2021b. Project 3102: jilin Nongan 50MW Biomass Power Plant Project URL: https://cdm.unfccc.int/Projects/DB/DNV-CUK1256582212.99/view (Accessed 17 March 2022).

Vera, R.M., Bura, R., Gustafson, R., 2015. Synergistic effects of mixing hybrid poplar and wheat straw biomass for bioconversion processes. Biotechnol. Biofuels 8, 226.

Visser, L., Hoefnagels, R., Junginger, M., 2020. Wood pellet supply chain costs – a review and cost optimization analysis. Renew. Sust. Energ. Rev. 118, 109506.

Wang, C., Xiujuan, L., Xiaoqian, S., Hongwen, L., 2001. Analysis of drought in summer of 2000 year in liaoning province. Water Resour. Hydropower of Northeast (In Chinese) 19, 6–8.

Wang, H., Wang, K., 2020. Comparative study on comprehensive benefits of biomass and coal power generation project. J. Arid Land Resour. Environ. (In Chinese) 34, 56–61.

Wang, S., Huang, X., Yin, C., Richel, A., 2021a. A critical review on the key issues and optimization of agricultural residue transportation. Biomass Bioenerg. 146, 105979.

Wang, S., Huang, X., Zhang, Y., Yin, C., Richel, A., 2021b. The effect of corn straw return on corn production in Northeast China: an integrated regional evaluation with meta-analysis and system dynamics. Resour. Conserv. Recy. 167, 105402.

Wang, X., Du, J., Wu, H., Xi, Y., Chang, Z., 2017. Analysis on straw storage and transportation cost using activity -based costing: a case study of Jiangsu Province, China. J. Agric. Resour. Environ. (In Chinese) 34, 10–16.

Wang, Z., Wang, Z., Xu, G., Ren, J., Wang, H., Li, J., 2020. Sustainability assessment of straw direct combustion power generation in China: from the environmental and economic perspectives of straw substitute to coal. J. Clean Prod. 273, 12289.

Wei, Q., 2014. Research On Supply Chain Logistics Cost of Straw For Biomass Power Generation. PhD Dissertation in China Agricultural University.

Wen, W., Zhang, Q., 2015. A design of straw acquisition mode for China's straw power plant based on supply chain coordination. Renew. Energ. 76, 369–374.

Wu, L., Chen, J., Zhu, X., Xu, Y., Feng, B., Yang, L., 2001. Straw burning in rural areas of China Causes and controlling strategy. China Popul. Resour. Environ. (In Chinese) 11, 111–113.

Wu, M., Wang, M., Huo, H., 2006. Fuel-cycle Assessment of Selected Bioethanol Production Pathways in the United States. Energy Systems Division. Argonne National Laboratory ANL/ESD/06-7.

Xing, A., Liu, G., Wang, Y., Wei, F., Jin, Y., 2008. Economic, energy and environment analysis on biomass collection process. Chin. J. Process Eng. (In Chinese) 8, 305–313.

Xu, X., Chen, Y., 2020. A comprehensive model to analyze straw recycling logistics costs for sustainable development: evidence from biomass power generation. Environ. Prog. Sust. Energ. 39, e13394.

Xu, Y., Yan, T., 2016. Analysis of willingness to sell straw and influencing factors of different types of concurrent business farmers——an empirical evidence from Shandong and Anhui provinces. Fiscal Sci. (In Chinese) 1, 95–106.

Yang, J., Huang, Z., Zhang, X., Reardon, T., 2013. The rapid rise of cross-regional agricultural mechanization services in China. Am. J. Agr. Econ. 95, 1245–1251.

Yang, X., Cheng, L., Huang, X., Zhang, Y., Yin, C., Lebailly, P., 2020. Incentive mechanism to promote corn stalk return sustainably in Henan. China. Sci. Total. Environ. 738, 139775.

Yin, H., Zhao, W., Li, T., Cheng, Xin., Liu, Q., 2018. Balancing straw returning and chemical fertilizers in China: role of straw nutrient resources. Renew. Sust. Energ. Rev. 81, 2695–2702.

Yu, X., Fan, F., 2009. Simulation analysis on fuel collection, processing, storage and transportation used in straw power plant in China. Trans. CSAE (In Chinese) 25, 215–219.

Yu, X., Wang, L., Wang, F., Xiao, J., 2013. Research on technology mode of corn straw collection and delivery in northeast area. J. Agric. Mech. Res. (In Chinese) 29, 24–28.

Zahraee, S.M., Shiwakoti, N., Stasinopoulos, P., 2020. Biomass supply chain environmental and socio-economic analysis: 40-Years comprehensive review of methods, decision issues, sustainability challenges, and the way forward. Biomass Bioenerg. 142, 105777.

Zhang, F., Guifa, T., Yingchun, Y., Kejian, W., Tiegang, F., Yuting, Z., 2018. Suitability selection of emergency scheduling and allocating algorithm of agricultural machinery. Trans. CSAE (In Chinese) 34, 47–53.

Zhang, F., Man, L., Shuhui, C., Zhe, Z., 2020. Research on route planning strategy of agricultural machinery operation -Based on intelligent agricultural machinery big data platform. J Agri. Mech. Res. (In Chinese) 36, 17–22.

Zhang, J., Zhang, W., 2021. The fuel technology for achieving carbon neutral in cement industry requires revolutionary breakthrough. China Energy Daily.

Zhang, Q., Zhang, F., Wu, G., Mai, Q., 2021. Spatial spillover effects of grain production efficiency in China: measurement and scope. J. Clean. Prod. 278, 121062.

Zhang, Q., Zhou, D., Zhou, P., Ding, H., 2013. Cost Analysis of straw-based power generation in Jiangsu Province. China. Appl. Energ. 102, 785–793.

Zhang, Q., Zhou, D., Fang, X., 2014. Analysis on the policies of biomass power generation in China. Renew. Sust. Energ. Rev. 32, 926–935.

Zhang, X., Yang, J., Thomas, R., 2017. Mechanization outsourcing clusters and division of labor in Chinese agriculture. China Econo. Rev. 43, 184–195.

Zhang, Y., Wang, F., Zhao, L., Sun, L., 2009. The operating model, existing problems and development strategies for China's straw storage and transportation system. Renew. Energy Resour. (In Chinese) 27, 1–5.

Zhao, Q., Cai, X., Mischo, W., Ma, L., 2020. How do the research and public communities view biofuel development? Renew. Sust. Energ. Rev. 133, 110265.

Zhao, Z.Y., Zuo, J., Wu, P.H., Yan, H., Zillante, G., 2016. Competitiveness assessment of the biomass power generation industry in China: a five forces model study. Renew. Energ. 89, 144–153.

Zubaryeva, A., Zaccarelli, N., Giudice, C.D., Zurlini, G., 2012. Spatially explicit assessment of local biomass availability for distributed biogas production via anaerobic co-digestion – Mediterranean case study. Renew. Energ. 39, 261–270.