INTEGRATED SPATIO-TEMPORAL TECHNO-ECONOMIC APPROACH FOR MODELING MULTI-SECTORAL BIOENERGY DEPLOYMENT

MUHAMMAD NURARIFFUDIN BIN MOHD IDRIS

UNIVERSITI TEKNOLOGI MALAYSIA

INTEGRATED SPATIO-TEMPORAL TECHNO-ECONOMIC APPROACH FOR MODELING MULTI-SECTORAL BIOENERGY DEPLOYMENT

MUHAMMAD NURARIFFUDIN BIN MOHD IDRIS

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

School of Chemical and Energy Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

DECEMBER 2021

ACKNOWLEDGEMENT

First and foremost, I would like to thank my supervisor Prof. Ir. Dr. Haslenda Hashim for giving me the opportunity to pursue this thesis under her supervision. Thank you for the years of insight and expertise on modeling and sustainable energy technology assessments. Thank you for your guidance, support and mentorship throughout the last five years, as well as your patience in the long process of developing the model.

I would also like to thank the many people who have provided great contributions to the work in this thesis and who I have collaborated with. I would like to thank my supervisors from the International Insitute for Applied Systems Analysis (IIASA), Dr. Sylvain Leduc, Dr. Florian Kraxner, Mr. Ping Yowargana, and Dr. Piera Patrizio. I will be forever grateful for the opportunity to collaborate on the development of the national-system model and for all their technical supports.

Special acknowledgement also deserves the Universiti Teknologi Malaysia (UTM), which partially provided funding for some of the research conducted in this thesis, Ferrero Trading Lux S.A. for supporting my participation in IIASA's Young Scientists Summer Program (YSSP), and IIASA for funding my research attachment to work on "Sustainable Bioeconomy Futures" project.

My sincere appreciation also extends to all my fellow friends who have provided their useful views, tips and assistance. They were always encouraging me with their best wishes. I hope that we keep our friendships in the coming years.

I could not have undertaken this PhD without the most important people in my life. I am extremely grateful to my loving parents, Mohd Idris Bin Saad and Rosnani Binti Ambiah, as well as my brothers and sisters, for their encouragement and support. I must thank them for their unrelenting prayers, guidance and support, without which I would not have achieved all that I have today.

To my beloved wife, Razlin Binti Mansor, thank you for making our life so special. Thank you for always being there for me, sharing my happiness when I was successful, and calming me down when I wasn't. Thank you so much for everything.

ABSTRACT

Although aspects of long-term planning are commonly taken into account in current analyses of bioenergy policy scenarios, spatial representations of the bioenergy supply chain are often overlooked. Multiple questions such as where, when, and how bioenergy is deployed thus have not been sufficiently addressed within a single modeling framework. Moreover, techno-economic models that can capture the dependencies of bioenergy supply chain variables among end-use sectors still need to be explored. This thesis presents a spatially and temporally explicit techno-economic supply chain optimization model that allows the assessment of bioenergy deployment at a higher system level from a multi-sectoral perspective. This thesis also presents applications of the model in the context of developing low-carbon pathways for a developing country having an economy reliant on fossil fuels and agriculture, with Malaysia serving as a case study. The model was developed in the generic algebraic modeling system, with ArcGIS applied for spatial processing and Python applied for database management. The first part of the thesis presents the model application for assessing long-term cross-cutting impact of implementing bioenergy in multiple energy sectors up to 2050. The findings suggest that integrating substantial capacity of bioenergy in Malaysia's energy sectors could help save up to 37% of the annual emission avoidance cost of meeting the long-term emission target. The findings also suggest that the renewable energy policies could deliver more emission reductions than the decarbonization policies, but would require 30% more cumulative investment. The second part of the thesis discusses more detailed strategies on how biomass co-firing with coal can contribute to meeting short-term emission target up to 2030, which is related to multi-scale production of solid biofuels from palm oil biomass to scale up co-firing. The findings show that densified biomass feedstock could substitute significant shares of coal capacities to deliver up to 29 Mt/year of greenhouse gas reduction. Nevertheless, this would cause a surge in the electricity system cost by up to 2 billion USD/year due to the substitution of up to 40% of the coal-fired plant capacities. The third part of the thesis presents the model application to analyze the impact of the co-deployment of co-firing and dedicated biomass technologies in contributing to the bioenergy cost reduction under the impact of incremental decarbonization targets and supply chain cost parameter variations. The findings suggest that the multi-sectoral deployment of bioenergy in energy systems is key to meeting decarbonization targets at the national scale. By also considering biomass co-firing with coal in the biomass technological pathway, up to 27% of bioenergy cost reduction could be enabled in the main case. All the findings from this thesis are expected to inform the ongoing policies and initiatives regarding greenhouse gas reduction, renewable energy production, and resource efficiency improvement for managing environmental sustainability.

ABSTRAK

Walaupun aspek perancangan jangka panjang biasanya dipertimbangkan dalam analisis semasa berkenaan senario melibatkan dasar biotenaga, aspek ruang dalam struktur rantaian bekalan biotenaga sering kali kurang diberi perhatian. Pelbagai persoalan seperti di mana, bila, dan bagaimana biotenaga dapat dibangunkan tidak dapat ditangani dengan cukup dalam satu kerangka pemodelan. Lebih-lebih lagi, model tekno-ekonomi yang dapat menghubung kebergantungan pemboleh ubah rantaian bekalan biotenaga di antara sektor penggunaan akhir masih perlu diterokai. Tesis ini mengemukakan model pengoptimuman rantaian bekalan tekno-ekonomi yang dilengkapi ciri-ciri pemodelan secara eksplisit dalam aspek ruang dan masa yang membolehkan penilaian pembangunan biotenaga pada tahap sistem yang lebih tinggi dari perspektif pelbagai sektor. Tesis ini juga mengemukakan aplikasi model dalam konteks pembinaan jalur rendah karbon untuk negara membangun yang ekonominya bergantung pada bahan bakar fosil dan pertanian, dengan menggunakan Malaysia sebagai kajian kes. Model ini telah dibangunkan di dalam pemodelan sistem algebra secara generik, menggunakan ArcGIS untuk pemprosesan ruang dan Python untuk pengurusan data. Bahagian pertama tesis membentangkan aplikasi model untuk menilai impak jangka panjang pelaksanaan biotenaga dalam sektor-sektor tenaga hingga tahun 2050. Hasil kajian menunjukkan bahawa integrasi kapasiti biotenaga yang secukupnya dalam sektor tenaga Malaysia dapat membantu menjimatkan hingga 37% kos penghindaran pelepasan tahunan untuk memenuhi sasaran pelepasan jangka panjang. Hasil kajian juga menunjukkan bahawa dasar-dasar berkenaan tenaga boleh diperbaharui dapat memberikan pengurangan pelepasan lebih banyak daripada dasar-dasar berkenaan penyahkarbonan, tetapi memerlukan lebih 30% pelaburan kumulatif. Bahagian kedua tesis membincangkan strategi yang lebih terperinci mengenai bagaimana pembakaran biojisim bersama arang batu dapat menyumbang pada pencapaian sasaran pelepasan jangka pendek hingga 2030, yang berkaitan dengan pengeluaran bahan api bio dalam bentuk pepejal pelbagai skala dari biojisim kelapa sawit untuk meningkatkan pembakaran biojisim bersama arang batu. Hasil kajian menunjukkan bahawa biojisim yang telah dipadatkan dapat menggantikan sebahagian besar kapasiti arang batu untuk menghasilkan pengurangan gas rumah hijau hingga 29 juta tan setiap tahun. Walaupun begitu, ini akan menyebabkan peningkatan kos sistem elektrik hingga USD 2 bilion setiap tahun disebabkan penggantian hingga 40% dari kapasiti loji pembuatan tenaga daripada arang batu. Bahagian ketiga tesis membentangkan aplikasi model untuk menganalisis kesan pembangunan bersama teknologi biojisim dan teknologi pembakaran bersama dalam menyumbang kepada pengurangan kos biotenaga di bawah kesan kenaikan sasaran penyahkarbonan dan perubahan parameter kos rantaian bekalan. Hasil kajian menunjukkan bahawa pembangunan biotenaga dalam pelbagai sektor sistem tenaga adalah kunci untuk memenuhi sasaran penyahkarbonan pada skala nasional. Dengan juga mempertimbangkan pembakaran biojisim bersama arang batu dalam pilihan teknologi biojisim, pengurangan kos biotenaga hingga 27% dapat dicapai dalam kes utama. Semua penemuan dari tesis ini dijangkakan dapat memberikan maklumat tentang dasar dan inisiatif mengenai pengurangan gas rumah hijau, pengeluaran tenaga boleh diperbaharui, dan peningkatan kecekapan sumber untuk mengurus kelestarian alam sekitar.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AD	-	Anaerobic digestion
B5	-	5% palm-biodiesel
B7	-	7% palm-biodiesel
B10	-	10% palm-biodiesel
B20	-	20% palm-biodiesel
B40	-	40% palm-biodiesel
BAU	-	Business-As-Usual
BECCS	-	Bioenergy with carbon capture and storage
BioCNG	-	Compressed biomethane
BNM	-	Bank Negara Malaysia
BSM	-	Specialized bioenergy supply chain model
CAPEX	-	Capital expenditure
CCI	-	Climate Change Initiative
CCS	-	Carbon capture and storage
CEPCI	-	Chemical Engineering Plant Cost Index
CHP	-	Combined heat and power
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
CPKO	-	Crude palm kernel oil
CPO	-	Crude palm oil
DEM	-	Digital Elevation Model
DML	-	Dry matter loss
EFB	-	Empty fruit bunch
EIA	-	United States Energy Information Administration
ESA	-	European Space Agency
ESM	-	Energy systems model
EU	-	European Union
FAME	-	Fatty acid methyl ester
FAO	-	Food and Agriculture Organization
FFB	-	Fresh fruit bunch

FiT - Feed-in Tariff
FT - Fischer-Tropsch
GAMS - General Algebraic Modeling System
GDP - Gross domestic product
GHG - Greenhouse gas emission
GIS - Geographical Information System
GTMP - Green Technology Master Plan 2017–2030
HCl - Hydrogen chloride
HF - Hydrogen fluoride
HHV - Higher heating value
IEA - International Energy Agency
INDC - Intended Nationally Determined Contribution
IPCC - Intergovernmental Panel on Climate Change
IRENA - International Renewable Energy Agency
ISO - International Organization for Standardization
IUCN - International Union for Conservation of Nature
JPPPET - Planning and Implementation Committee for Electricity and Supply Tariff of Malaysia
KRI - Khazanah Research Institute
LCA - Life cycle assessment
LHV - Lower heating value
LNG - Liquefied natural gas
LP - Linear programming
LSS - Large Scale Solar
LULUCF - Land use, land-use change, and forestry
MC - Moisture content
MCDA - Multi-criteria decision making
MF - Mesocarp fibre
MILP - Mixed-integer linear programming
MPOB - Malaysian Palm Oil Board
MSW - Municipal solid waste
NDC - Nationally Determined Contribution
NEM - Net Energy Metering
NKEA - National Key Economic Area

NO_2	-	Nitrogen dioxide
NREPAP	-	National Renewable Energy Policy and Action Plan 2009
O&M	-	Operation and maintenance
OER	-	Oil extraction rate
OPF	-	Oil palm frond
OPT	-	Oil palm trunk
Petronas	-	Petroleum Nasional Berhad
PKS	-	Palm kernel shell
PM	-	Particulate matter
POME	-	Palm oil mill effluent
RE	-	Renewable electricity
RH	-	Rice husk
RPR	-	Residue-to-product ratio
RS	-	Rice straw
SO_2	-	Sulfur dioxide
SREP	-	Small Renewable Energy Policy
SSR	-	Self-sufficiency ratio
UNFCCC	-	United Nations Framework Convention on Climate Change
UK	-	United Kingdom
US	-	United States

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

1.1.1 Roles of Bioenergy in Energy Systems Decarbonization

Climate change is one of these century's defining challenges, creating new impediments to the already existing development threats [1]. Anthropogenic greenhouse gas (GHG) emissions are appraised to have contributed to global warming of between 0.8 and 1.2 °C above pre-industrial levels [2]. Without drastic measures taken, this global warming rate is expected to rise by an additional of 2.5–7.8 °C by the end of this century [2,3]. To mitigate the impact of climate change, countries of the world have pledged their commitments in the Paris Agreement to reduce their overall GHG emissions.

In meeting the climate stabilization target of limiting global temperature rise to 1.5 °C above pre-industrial levels, large amount of biomass resources will be demanded to deliver significant bioenergy capacities for delivering energy system decarbonization [4]. According to the Intergovernmental Panel on Climate Change (IPCC) report, reaching the climate change mitigation goal will necessitate up to 430 EJ/year of biomass use by 2100, as well as the phase-out in fossil fuel consumption and increased use of other renewables [5]. The ratio of bioenergy to global primary energy consumption would constitute to up to 50% by the end of the century from an average of 10% currently [6,7]. To meet this commitment, the contribution of biomass to meet future energy demands would be based on the utilization of both dedicated energy crops (e.g., miscanthus, swithgrass, jatropha) and residues (e.g., forestry residues, milling residues, agricultural residues) [8]. By 2050, global potentials of biomass (including energy crops and residues) that can technically be mobilized for bioenergy were identified ranging from < 50 EJ/year to > 500 EJ/year [5].

Biomass has the potential to contribute to climate change mitigation due to its ability to remove carbon dioxide (CO_2) from the atmosphere when managed in a sustainable way [4]. When biomass is used to substitute fossil fuels, the biogenic CO_2 captured in biomass is released back to the atmosphere, resulting in a neutral CO_2 emission cycle, therefore, avoiding the fossil CO_2 emitted to the atmosphere [9]. The CO_2 reduction potential that can be contributed by biomass may reduce when the emissions from its supply chain activities (e.g., cultivation, harvesting, processing, transportation) are taken into account [10]. However, studies have shown that many bioenergy production routes still provide significant CO_2 reduction potential although the supply chain emissions are included in the life-cycle CO_2 accounting [10,11,12]. To deliver large-scale biomass capacity to meet future demand, the potential mitigation services that these resources can provide must be optimally assessed.

The benefit of large-scale biomass-based routes compared to other renewables for delivering energy system decarbonization is the versatility of biomass resources that can be converted to varieties of value-added products for uses in different sectors such as power, heat and transport [13]. Also, for each of the biomass types, there are several production pathways possible. For example, biomass can be converted into different types of liquid or gasesous fuels such as biomethanol, bioethanol, biodiesel, biogasoline, biomethane and biohydrogen aside from its conventional uses for bioelectricity and bioheat production [14]. The multi-sectoral benefit of biomass to produce variety of products provides means of decarbonizing other sectors beyond power [13]; however, cost of pursuing advanced bioenergy routes is still high [15]. Although it is estimated that the cost of biomass energy would be reduced in future due to learning effect [16], decarbonization strategies should be planned earlier to avoid further ‘lock-in’ of energy system into fossil fuels [17]. For instance, according to Riahi et al. [17], if the near-term low-carbon energy target is not met by 2030, the long-term low-carbon energy commitment in 2050 would be increased by up to 200%, due to the delayed action to scale up mitigation efforts. Prioritization of the most cost-effective production routes deployed in different planning timeframes (e.g., short, medium, and long-term) should thus be defined in order to avoid or minimize this ‘lock-in’ impact [15,17].

While cost is an important indicator for evaluating the value of different biomass conversion routes within the energy systems [4], the decarbonization potentials are also affected by other indicators such as biophysical parameters (e.g., biomass properties), process specifications (e.g., energy efficiency), regional variations (e.g., land availability, yield), and the counterfactual scenario analyzed, among others, which influence the relative mitigation potential of each pathway [18]. Understanding the optimum usage of this limited resource in relation to the geographical context and the rate of decarbonization of the energy system is therefore crucial.

1.1.2 Bioenergy Planning for Multi-Sectoral Energy Decarbonization

To mitigate climate change by reducing GHG emissions, transition from fossil-fuel to renewable energy use is actively promoted around the world. The idea of the bio-based economy has gained much traction as a strategy to contribute to energy transition [19,20]. A promising approach is advanced bioenergy production which has the potential to decarbonize different emission-intensive sectors such as power, heat, and transport [21,22]. There will be increasing demand for agricultural products that provide sustainable sources of feedstock for bioenergy production during transition [23,24].

As agricultural production is typically distributed over large areas of land, the allocation of feedstock resources is commonly associated with high transportation costs. The retrieval of bioenergy feedstock at a higher system scale advocates for effective management of logistics systems to handle supply chain activities in a commercially viable way. Logistics are often interlinked with, for example, resource supply and availability [25,26], production scales and locations [27,28], intermodal transport [29,30] and supply chain configurations [31,32]. The cost-minimization approach has been frequently applied to examine the trade-off between the elements or variables of the supply chain.

Adopting a whole-system view in decision making is crucial in minimizing the risk of oversimplifying the representation of the problems. Spatio-temporal approach can potentially capture a system view of the energy supply chain while addressing several problems related to time-dependent, location-dependent, and techno-economic decision factors [33]. For instance, selecting suitable locations for bioenergy facilities can help reduce logistical costs [31] and provide integration benefits to existing industries [34]. Moreover, some local characteristics of the supply chain, such as feedstock availability and demand, both of which are highly influenced by spatial and temporal variabilities, can be addressed systemically in the planning [35]. Integration of higher system level studies with the appropriate technology details at the plant level can potentially improve the existing framework for solving bioenergy issues related to the intensive use of bioenergy resources for multi-sector energy purpose.

In recent years, several studies have been conducted to explore spatio-temporal bioenergy supply chain designs that integrate high spatial resolution with long-term planning objectives. Leduc et al. [36] presented an optimization model (the BeWhere model) with a spatial resolution of 0.1° (10 km x 10 km) that determines the optimal locations of forest biomass–based methanol production plants in Sweden for the 2005–2025 period. Johnson et al. [37] presented an integrated assessment to investigate the development of supply curves of biofuel (from energy crops and agricultural residues) with carbon capture and storage (CCS) in the United States (US) during 2020–2050 at a district-level spatial resolution. Samsatli et al. [38] developed an optimization model (the BVCM model) with a spatial resolution of 0.5° (50 km x 50 km) and multi-level temporal resolutions (i.e., decade, year, season) that incorporates a comprehensive biomass value chain pathway for the United Kingdom (UK) and covers multiple types of feedstock from waste and agricultural residues to energy crops and forest biomass. Leila et al. [39] investigated the spatio-temporal supply chain design of renewable diesel and biojet fuel in California for the 2020–2040 period at a district-level spatial resolution. Patrizio et al. [40] investigated the long-term socioeconomic impact of forest-based bioenergy with carbon capture and storage (BECCS) in the US for the 2020–2050 period using an integrated assessment approach (BeWhere-JEDI) at a spatial resolution of 0.5° (50 km x 50 km). Truong et al. [41] assessed the near-term CO_2 emission implication of co-fired paddy residues in Vietnam’s coal plants for the

2016–2030 period using a recursive-dynamic modeling approach (BeWhere-Vietnam) with a spatial resolution of 0.2° (20 km x 20 km). Zhang et al. [42] presented a bottom-up assessment of a spatio-temporal BECCS design that includes the utilization of wastes, agricultural residues, energy crops, and forest biomass as bioenergy feedstocks for the UK for 2030-2050 at a spatial resolution of 0.5° (50 km x 50 km). Fajardy and Mac Dowell [43] applied the MONET modeling framework with its multi-level spatial resolutions (i.e., country, state) to investigate the efficacy of a multi-country collaboration in terms of delivering global CO_2 removal through BECCS deployment for 2030–2100.

Other than the reviewed studies pertaining to spatio-temporal bioenergy supply chain designs, much of recent work has focused on the application of energy systems models to provide insights into bioenergy policy scenario analysis. Such work has illustrated the significance of scenario analysis as a tool for informing long-term policy decisions at a system level. However, the supply chain boundaries considered were often spatially aggregated based on a single-node/coarser spatial representation. Several examples of the policy scenarios discussed in these studies were presented. Börjesson et al. [44] applied the MARKAL_Sweden model to the case of bioenergy in Sweden to analyze scenarios involving national targets on 80% CO_2 reduction compared to 1990 level by 2050 and 100% fossil fuel phase-out in the transport sector by 2050. Thrän et al. [45] applied the MILESTONE modeling framework to the case of bioenergy in Germany to analyze scenarios involving bioenergy provisions under different land use sustainability criteria and technology prioritization for the 2015–2050 period. Pan et al. [46] applied the GCAM modeling framework to the case of bioenergy in China to analyze scenarios involving BECCS deployment under net-zero and net-negative emission targets. Durusut et al. [21] developed a new techno-economic model (the BioHEAT model) that accounts for the co-dependencies of bioenergy among end-use energy sectors and incorporates consumer decision-making in the heat sector. The BioHEAT model was applied to the case of bioenergy in Ireland to analyze scenarios involving multiple policies adopted in the power, heat, and transport sectors, such as the implementation of a co-firing rate of up to 60% in peat-fired stations by 2030, a mandated renewable transport fuel target of up to 14% by 2030, and extension of the price support scheme for renewable heat to 2030 [22].

In the literature mentioned, there was only limited assessment of the long-term cross-cutting impacts of implementing bioenergy in multiple energy sectors (i.e., power, heat, and transport) in a spatially and temporally explicit manner. This is important because, in order to take advantage of the versatility of bioenergy in working with different energy carriers, there needs to be a strategy that can deliver multi-sector interactions to ensure effective allocation of resources to the right sector. Such a strategy could inform policy conflicts between the achievement of renewable energy and emission-reduction targets in the energy sectors. Although the studies conducted by Durusut et al. [21] and Clancy et al. [22] have presented the modeling insights for the decarbonization of multiple energy sectors from a policymaker's perspective, the energy system boundary was aggregated based on a single-node location representation, which might overlook the cost analysis details that a more comprehensive representation of the bioenergy supply chain network could provide. Furthermore, the bioenergy location-allocation network adopted in these studies were aggregated in which trade-offs between distributed and centralized configuration of facilities, transportation modes, and economies of scales were not considered. On the other hand, integration of seasonal temporal resolution into a long-term modeling approach, which is limited in the studies mentioned above (only addressed by Samsatli et al. [38]), should be explored further for the case of multi-sectoral bioenergy supply chain designs. The tactical/operational elements adopted in the supply chain configuration could improve cost quantification of the overall system by accounting for the resource storage cost. This would also improve the selection of bioenergy feedstock due to the trade-off between the seasonal reliabilities and the supply cost.

Overall, it can be concluded that the existing techno-economic models used for bioenergy planning at the national level have not been sufficiently addressing the important challenges in handling critical bioenergy issues, i.e., supply chain complexity, cross-sectoral bioenergy interactions between end-use sectors, spatial tractability of bioenergy supply chain, and temporal tractability of bioenergy decisions, in an integrated manner. Therefore, a new integrated whole-system model is needed to simultaneously address these research gaps in order to add new bioenergy insights into the existing body of knowledge based from a spatio-temporal, multi-sectoral, techno-economic perspective.

1.1.3 Multi-Sectoral Bioenergy Opportunities in Malaysia

In December 2015, Parties of the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement to address climate change [47]. Parties agreed to keep the increase in global average temperature to well below 2 °C above pre-industrial levels, and to pursue efforts to stay below 1.5 °C. Many Parties also formulated and submitted Intended Nationally Determined Contribution or INDC [48] that outlines the near-term climate action plans to be taken under the Paris Agreement. After the Agreement entered into force in November 2016, the INDC for those countries that have ratified the Agreement were converted into Nationally Determined Contributions (NDC) [49]. The NDCs outlined have addressed a range of issues, related to avoiding, adapting or coping with climate change, among other things. Nevertheless, targets and actions for reducing GHG emissions are core components [50]. Limiting global warming based on this climate challenging goal will entail a dramatic transformation of the global energy system. Emissions reduction commitments for the near term which are highly needed in mitigating the GHG, raise an important question for the international climate policy on how it affects the interventions at the national level, and also, on how the developing countries will cope with the development of sustainable energy in the future.

Heavy reliance by Malaysia on fossil fuels for the next few decades (as shown in Figure 1.1) [51] will require the country to mitigate its GHG levels to meet its national emission reduction commitment under the Paris Agreement. This requires Malaysia to reduce the emission intensity of its gross domestic product (GDP) by 35% by 2030 on an unconditional basis relative to the 2005's level, with a further 10% reduction conditional upon receipt of international funding from developed countries [52]. The majority of Malaysia's GHG emissions are from the energy sector [53], suggesting the importance of the role of renewable energy in decarbonizing future energy systems. Policies regarding the development of renewable energy in Malaysia currently focus on two main strategies which are renewable electricity (RE) capacity expansion to achieve 20% of the electricity mix by 2025 [54] and mandatory road transport fuel blending with 20% palm-biodiesel (B20) starting from 2020 [55]. Achieving these targets within just a short timeframe could be challenging for

Malaysia, as the present RE mix is still less than 2% [56] and the 10% palm-biodiesel (B10) mix mandate was implemented only in 2019 [57]. There is thus limited time available to increase the capacities of renewable energy in the power and transport sectors.

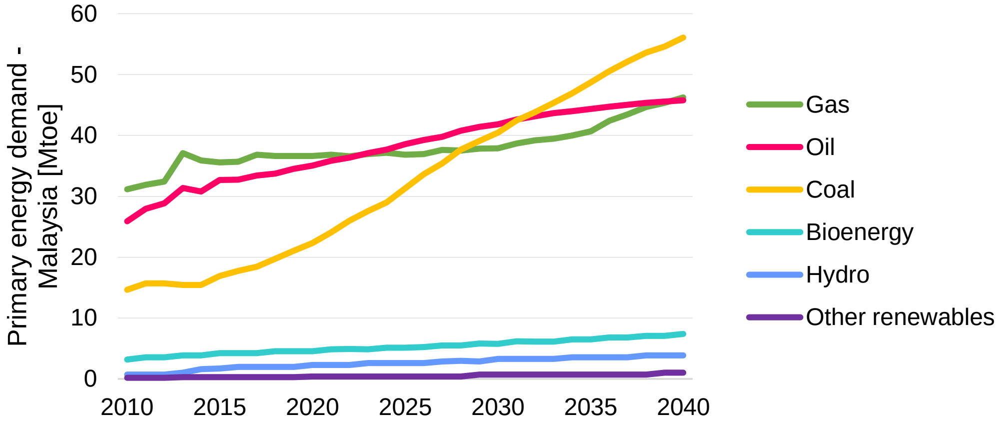

Figure 1.1 Primary energy demand projection by fuel for Malaysia under the business-as-usual case [51]

Bioenergy is considered one of the promising substitutes for fossil fuels in reducing GHG as it provides renewable carbon source for energy generation. The carbon content in biomass is derived from the atmospheric CO_2 which is sequestered during photosynthesis [58]. Further biomass conversion into bioenergy could result in net neutral (on the basis where supply chain emissions are excluded in the GHG accounting) or nearly net neutral (on the basis where supply chain emissions are included in the GHG accounting) CO_2 emissions as the CO_2 sequestered in biomass during photosynthesis is released back to the atmosphere during the final use of bioenergy (e.g., bio-based fuel consumption in internal combustion engine of a vehicle, biomass combustion to produce electricity and heat) [58,59]. Bioenergy, by leveraging the potentials of feedstock that can be mobilized from the agricultural sector, mainly palm oil resources, has the potential to increase capacity for renewables in Malaysia while mitigating greenhouse gases. Bioenergy resources can be converted into various value-added products for use in different sectors such as power, heat, and transport [21]. Although utilization of these resources offers a promising strategy for decarbonization across different sectors, careful attention is required to several issues at the supply chain level. Regarding resource supply, securing biomass for bioenergy is still a major challenge for Malaysia, considering the widespread practices of biomass combustion for onsite cogeneration in mills [60] and mulching in the plantations [61]. This is added with the issue on limited biomass hubs availability at the local level for collection purposes [60] which could help in improving the reliability of supply. Freeing up the way biomass is currently used for applications that have higher economic potential, such as large-scale power and heat, transport biofuels, and biochemicals could be means of scaling-up bioenergy at the national scale, although it would make supply chain design more complex. This complexity is due to the various stages in the bioenergy supply chain, such as harvesting, collection, storage, transport, conversion, and distribution [62]. Thus, for any bioenergy deployment strategy to be viable, its deployment pathway must be configured for cost-effectiveness [31].

Discussions on the role of bioenergy in the long-term decarbonization of the currently dominated fossil fuel-based energy system in Malaysia are still limited. The consideration of both fossil fuels and renewables in the technological pathway to meet national energy demand is important to cater the energy price market competition in delivering decarbonization targets. Previous studies have provided several insights into the implications of implementing certain strategies to reduce future emissions [63,64,65] but lacking in the cost analysis details to inform policy. Among these studies, considerations of utilizing palm oil residues for bioenergy production to secure future electricity supply and reduce emissions have been discussed by Muis et al. [64] but only with respect to the Iskandar Malaysia region. On the other hand, the decarbonization pathways in these studies, although including both renewables and fossil fuels in the pathway, were limited to only one sector, either electricity or transport, overlooking the potential cost reduction opportunities in multi-sector collaborations.

Conducting assessment at a wider system level is important since it presents the opportunity to leverage the full potential of resources for bioenergy production. This can be represented by the Malaysia case, where expanding the focus of bioenergy planning to also include Malaysian Borneo on top of Peninsular Malaysia which has been the focus region of interest in the previous works could indicate greater potential of increasing renewable energy capacities in the country, provided by the latter region has larger areas of oil palm plantations than the former [66]. Furthermore, the importance of considering higher system scale can be shown by the case involving main palm oil producing countries (e.g., Malaysia and Indonesia), where there exists the need to handle the complexity of resource trades between the regions within these countries, for example, the trades of palm oil resources between Peninsular Malaysia and Malaysian Borneo for the case of Malaysia and the trades of palm oil resources between Sumatra and Kalimantan for the case of Indonesia, due to the associated geographical boundaries of the regions within these countries which are separated by the coastal areas.

It must be highlighted that cross-sectoral policy interventions are essential for the long-term assessment of bioenergy deployment. This is important, as the promotion of bioenergy uses in one sector of the energy system can stimulate or decrease the uptake in the others, and this affects the allocation of resources and policies to support the future bioenergy. The mobilization of biomass from agricultural sector for the production of multiple value-added products, especially bioenergy, can be seen as a promising strategy to promote low-carbon energy production in Malaysia, and thus, to explore its potential, national system-level deployment of bioenergy becomes the main focus of investigation this thesis.

1.2 Problem Statement

The decarbonization potentials that bioenergy could bring are impacted by many system-level deployment challenges, particularly related to different aspects of bioenergy supply chain planning. From the reviews above, the bioenergy deployment challenges that need to be addressed include (1) supply chain complexity (i.e., feedstock-technology-production relation, supply and demand balancing, distributed versus centralized supply chain configuration, trade-offs between transportation requirement and economies of scales), (2) cross-sectoral bioenergy interactions between end-use sectors (i.e., bioenergy market price competition with fossil fuels, bioenergy interaction in energy systems, sectoral policy versus multi-sectoral bioenergy policies), (3) spatial tractability of bioenergy supply chain (i.e., feedstock supply, bioenergy demand, candidate bioenergy facilities, competition of resources, infrastructure network expansion) and (4) temporal tractability of bioenergy decisions (i.e., long-term planning aspect for accounting strategic decisions, short-term planning aspect for accounting operational/tactical decisions). Although much studies have been conducted to analyze a variety of different bioenergy issues, the insights derived from their findings are still not sufficient to address all of these bioenergy challenges simultaneously under one integrated modeling platform. This calls for new studies to inform these knowledge gaps in research. Following are the specific research gaps identified on the existing bioenergy assessment at a system level:

(1) Existing techno-economic models used for bioenergy planning were primarily based on the applications of energy systems model (ESM) (e.g., MARKAL, TIMES, MESSAGE, EnergyPLAN, BioHEAT) to address strategic bioenergy decisions and specialized bioenergy supply chain model (BSM) (e.g., BeWhere, BVCM, OPTIMASS, BENSIM, MONET, other bespoke bioenergy models) to address operational and tactical bioenergy decisions. ESMs have an advantage over BSMs in terms of their rich technological representations and long-term planning horizon for multi-sectoral analyses, making them suitable to be applied for informing broader energy systems and policy issues; however, their energy supply chain representations were often aggregated and single-node spatial representations were commonly used. Due to this aggregation, difficulties arise in recognizing the complex underlying impacts of the detailed bioenergy supply chain in ESMs, which could have been recognized more explicitly in BSMs. BSMs have an advantage over ESMs in terms of their detailed representation of bioenergy supply chain flow (i.e., cultivation, harvesting, transport, storage, pre-processing, conversion, distribution); however, most of the BSMs developed for application at the national level offer bespoke analyses based on targeted bioenergy issues and the broader cross-sectoral impacts of energy systems are often overlooked. It is therefore important to integrate the long-term multi-sectoral features of ESMs with the detailed bioenergy supply chain representation presented in BSMs in one integrated modeling platform so that different challenges in bioenergy planning mentioned above (i.e., supply chain complexity, multi-sectoral bioenergy interactions, spatial

tractability, temporal tractability) can be addressed simultaneously to deliver more well-rounded bioenergy assessment.

(2) There is also a necessity in improving the establishment of spatially-explicit bioenergy potentials as exogenous inputs into the techno-economic models when applying spatio-temporal approach. Instead of relying on processed land-use data from other studies, the application of land cover assessment method based on a high-resolution spatial data processing approach could improve the establishment of exogenous feedstock availability, candidate bioenergy facility locations and energy demand profiles in the techno-economic model. As the existing works that combine land cover assessment methodology with either ESMs or BSMs are still limited in literature, incorporating land cover assessment methodology into the techno-economic optimization framework could help improve the geographical coverage of bioenergy potential that can be allocated for use in energy systems.

It must be mentioned that no study has previously been conducted to address the aforementioned research gaps outlined collectively. Given these gaps in literature, this thesis aims to bridge these three different fields of studies, namely ESM, BSM, and land cover assessment, that address different challenges in bioenergy modeling (i.e., supply chain complexity, multi-sectoral bioenergy interactions, spatial tractability and temporal tractability) at a higher system level. This thesis is motivated to fill the gaps by providing a novel methodological framework that focuses on a multi-sectoral approach for spatio-temporal techno-economic modeling and optimization of bioenergy supply chain. The assessment provided is expected to contribute new knowledge to the existing body of knowledge, based on an integrated techno-economic model developed and a series of novel cases modeled. The problem statement for this research is stated as follows:

Given the key issues outlined related to spatial, temporal, technical, economic, environment and policy elements of the bioenergy deployment, it is desirable to improve the existing assessment by developing a multi-sectoral approach to the modeling and optimization of bioenergy supply chain for generating near-term and long-term insights on the cross-sectoral energy decarbonization opportunities at a higher system level.

1.3 Research Objectives

The aim of this thesis is to expand the knowledge on the development and application of an integrated techno-economic optimization model for informing near-term and long-terms insights on bioenergy deployment at a wider regional scale in a spatial and temporal explicit manner from multi-sectoral perspectives. The specific research objectives of this thesis are outlined as follows:

(1) To develop an integrated techno-economic optimization model for multi-sectoral bioenergy deployment in a spatially and temporally explicit manner based on combining bioenergy supply chain optimization modeling and long-term energy systems planning approaches (**OBJ1**).

(2) To perform system-level scenario modeling and analysis in generating near-term and long-term insights on the multi-sectoral bioenergy deployment and energy decarbonization for a period of up to 2050 (**OBJ2**).

(3) To evaluate the impact of energy decarbonization targets, technology availability and supply chain cost parameter variations to promote cost-effective decarbonization of emission-intensive energy sectors at a system level (**OBJ3**).

1.4 Scopes of the Modeling Works

Based from the research objectives mentioned, the modeling and scenario analysis performed in the thesis are systematically methodologized based on the following scopes:

(1) Analyzing the state-of-the-art methodology and knowledge on bioenergy supply chain modeling and long-term energy systems planning, including the associated features, shortcomings and potential improvements.

(2) Identifying sets of candidate bioenergy feedstock, technologies, products, logistics and infrastructures required for the development of bioenergy supply chain pathway.

(3) Performing data collection from various sources (i.e., scientific journals, technical reports/documents, governmental reports/documents, international organization reports/documents, international standards, online institutional datasets and national statistics) on the associated bioenergy feedstock, technologies, products, logistics and infrastructures, based from the spatial, temporal, technical, economic, environment and policy aspects of the developed bioenergy supply chain pathway.

(4) Establishing the spatio-temporal input modeling database through a series of data processing workflow involving the use of high-resolution spatial data processing tools in geographical information system (GIS) for resource availability analysis, energy demand analysis, site suitability analysis, and transport network analysis.

(5) Establishing the input modeling database for bioenergy technologies by performing techno-economic calculation to establish sizes, investment costs, operating costs, conversion efficiencies, and GHG emission profiles for each bioenergy technology.

(6) Developing an integrated techno-economic optimization model that accounts for the current state-of-the-art methodology on bioenergy supply chain modeling and long-term energy systems planning, featuring the spatial, temporal, technical, economic, environment and policy aspects of the developed bioenergy supply chain pathway.

(7) Developing and modeling scenarios on the near-term and long-term bioenergy strategies for the related cases involving integration of agriculture-based bioenergy from intensive palm oil-based sources in multiple energy sectors for cross-sectoral energy decarbonization at a system level.

(8) Developing and modeling sensitivity scenarios to assess the sensitiveness of the bioenergy cost reduction potentials and bioenergy deployment with and without biomass co-firing toward variations in the decarbonization targets and the supply chain cost parameter values at a system level.

(9) Analyzing the results generated from the modeling works and addressing the questions outlined.

(10) Bioenergy feedstock: Agricultural-based bioenergy feedstock (i.e., crude palm oil (CPO), EFB, MF, PKS, OPF, OPT, POME, rice straw (RS), rice

husk (RH)) and livestock-based bioenergy feedstock (i.e., cattle, buffalo, sheep, goat, chicken and duck manures).

(11) Energy sectors covered: Power (coal-based electricity production as a reference energy competitor), heat (industrial natural gas-based heat demand as a reference energy competitor), and transport (gasoline- and diesel-based transport fuel demands as reference energy competitors).

(12) Bioenergy technologies: Biomass pre-processing (i.e., drying, pelletization), biogas pre-processing (i.e., biomethane, BioCNG), biogas-to-bioelectricity, biomass-to-bioelectricity, biomass co-firing, biomass CHP, biomass-to-biofuel and crop-to-biofuel.

(13) Geographical boundaries: Malaysia (Peninsular Malaysia and Malaysian Borneo).

(14) Spatial resolution: 0.25° (25 km x 25 km), multi-plant, multi-state, and multi-harbor.

(15) Temporal resolution: 2020–2050 (5-year time step) and 2-month sub-annual time steps.

(16) Software: ArcGIS [67] for spatial data processing, Generic Algebraic Modeling System (GAMS) [68] for mathematical formulation of the spatio-temporal techno-economic optimization model, Microsoft Excel [69] for database storage, and Python [70] for the automation of the modeling workflow.

1.5 Thesis Contributions

The main contribution of this thesis is the addition of new knowledge in the fields of bioenergy supply chain modeling and long-term energy systems planning, focusing on the multi-sectoral approach to spatio-temporal techno-economic modeling and optimization of bioenergy deployment in multiple energy sectors through large-scale utilization of local bio-based resources from palm oil sources and other agricultural crops. An integrated modeling tool was resulted from this thesis which can be applied by policymakers, industrial players and researchers for generating interdisciplinary perspectives to inform policies and development at a national level, especially from a low-carbon pathway development context. These perspectives are useful to inform the wider social debate on the options to decarbonize energy across multiple national sectors. The related sectors include the agricultural sector, regarding the opportunity to maximize resource efficiency of agricultural productions and operations through the effective uses of agricultural wastes for value-added purposes, the power sector, regarding the potential of bioenergy to increase the renewable energy shares in the power mix and substitute significant portion of fossil fuel-based base load, the industrial sector, regarding the use of waste heat from bioenergy production as an industrial heat substitute for natural gas, the transport sector, regarding the use of biofuels in supporting the existing biodiesel program, and the energy sector in general, regarding the range of GHG emission that could be mitigated at the national scale in the short, medium and long-term timeframes. The new knowledge resulted from this thesis can be used to inform the development of the next cycles of NDC's biennial update reports to the UNFCCC.

1.6 Thesis Outline

The structure of this thesis consists of seven chapters as shown in Figure 1.2. Chapter 1 presents the research background, problem statement, research objectives, research scopes and research contributions associated with the thesis. Chapter 2 reviews the current state-of-the-art in the fields of bioenergy supply chain modeling and long-term energy systems planning and highlights the literature gaps associated with the research questions of the thesis. Chapter 2 also provides the background information of the case study's country in terms of its agriculture, energy, and emission policies (particularly NDC). Chapter 3 describes the methodological framework used in this thesis and the specific workflow associated with the framework. Noted that the methodology presented in Chapter 3 addresses the first objective of the thesis. Chapter 4 then presents the application of the integrated spatio-temporal techno-economic optimization model developed for scenario modeling and analysis on the long-term agricultural bioenergy strategies for cross-sectoral energy decarbonization. Note that the scenarios analyzed in Chapter 4 address the second objective of the thesis regarding the long-term insights of multi-sectoral bioenergy deployment. Based from the specific results from Chapter 4 which highlighted that co-firing would play a major role in near-term energy decarbonization, Chapter 5 presents the application of the model to investigate how multi-scale production of solid biofuels from oil palm biomass can scale up biomass co-firing with coal. Note that the scenarios analyzed in Chapter 5 also address the second objective of the thesis regarding the near-term insights of bioenergy deployment. The sensitiveness of bioenergy development in multiple energy sectors are evaluated in Chapter 6 and this addresses the third objective of the thesis. Lastly, the work is concluded in Chapter 7 with the main findings of the thesis together with the limitations of the research and the recommendations for improvement in future work. All the scientific publications related to the research presented in this thesis are listed in the appendix.

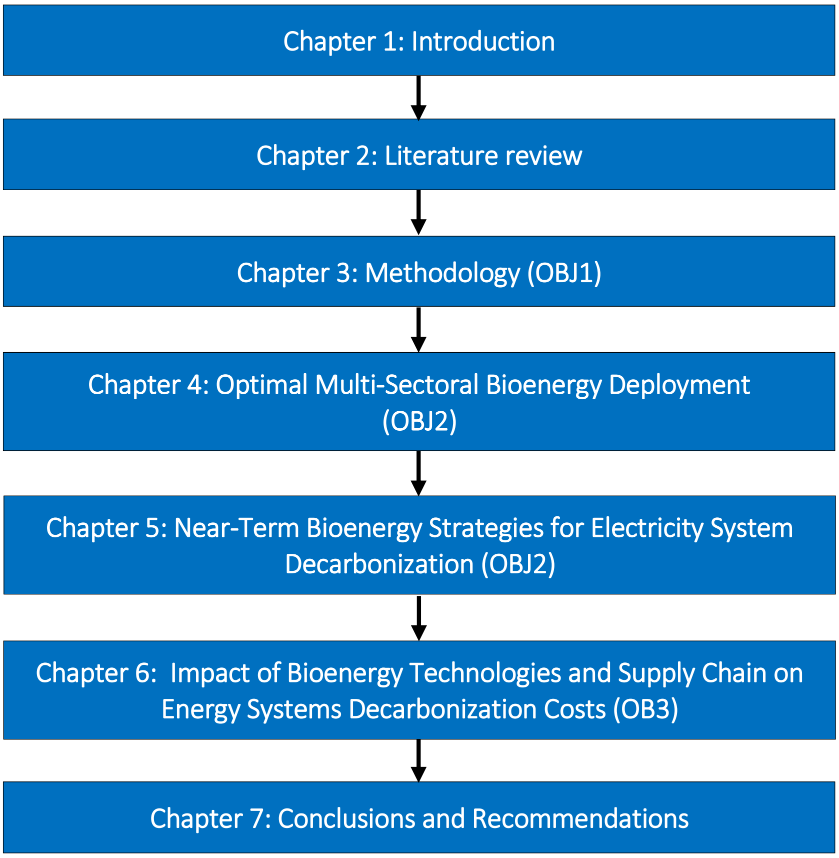

Figure 1.2 Thesis outline

REFERENCES

1. OECD. *Aligning Development Co-operation and Climate Action: The Only Way Forward, The Development Dimension*. Paris, France: OECD Publishing. 2019.
2. IPCC. Summary for Policymakers. In: Masson-Delmotte, V., Zhai, P., Pörtner, H. O., Roberts D., Skea, J., Shukla, P. R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J. B. R., Chen, Y., Zhou, X., Gomis, M. I., Lonnoy, E., Maycock, T., Tignor, M. and Waterfield, T. eds. *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Geneva, Switzerland: World Meteorological Organization. pp. 32; 2018.
3. UNFCCC. *Adoption of the Paris Agreement and Annex: Paris Agreement*. Paris, France: United Nations Framework Convention on Climate Change. 2015.
4. Patrizio, P., Fajardy, M., Bui, M. and Mac Dowell, N. CO_2 Mitigation or Removal: The Optimal Uses of Biomass on Energy Systems Decarbonization. *iScience*. 2021. 24:102765.
5. Rogelj, J., Popp, A., Calvin, K. V., Luderer, G., Emmerling, J., Gernaat, D., Fujimori, S., Strefler, J., Hasegawa, T., Marangoni, G. and Krey, V. Scenarios towards Limiting Global Mean Temperature Increase Below 1.5 C. *Nature Climate Change*. 2018. 8: 325-332.
6. Rose, S. K., Kriegler, E., Bibas, R., Calvin, K., Popp, A., van Vuuren, D. P. and Weyant, J. Bioenergy in Energy Transformation and Climate Management. *Climatic Change*. 2014. 123: 477-493.

7. Shahbaz, M., AlNouss, A., Ghiat, I., Mckay, G., Mackey, H., Elkhalifa, S. and Al-Ansari, T. A Comprehensive Review of Biomass Based Thermochemical Conversion Technologies Integrated with CO_2 Capture and Utilisation within BECCS Networks. *Resources, Conservation and Recycling*. 2021. 173: 105734.

8. Wu, W., Hasegawa, T., Ohashi, H., Hanasaki, N., Liu, J., Matsui, T., Fujimori, S., Masui, T. and Takahashi, K. Global Advanced Bioenergy Potential under Environmental Protection Policies and Societal Transformation Measures. GCB Bioenergy. 2019. 11: 1041-1055.

9. Bui, M., Fajardy, M. and Mac Dowell, N. Bio-energy with Carbon Capture and Storage (BECCS): Opportunities for Performance Improvement. *Fuel*. 2018. 213: 164-175.

10. Liu, B. and Rajagopal, D. Life-Cycle Energy and Climate Benefits of Energy Recovery from Wastes and Biomass Residues in the United States. *Nature Energy*. 2019. 4: 700-708.

11. Beagle, E. and Belmont, E. Comparative Life Cycle Assessment of Biomass Utilization for Electricity Generation in the European Union and the United States. *Energy Policy*. 2019. 128: 267-275.

12. Li, G., Cui, P., Wang, Y., Liu, Z., Zhu, Z. and Yang, S. Life Cycle Energy Consumption and GHG Emissions of Biomass-to-Hydrogen Process in Comparison with Coal-to-Hydrogen Process. *Energy*. 2020. 191: 116588.

13. Röder, M., Mohr, A. and Liu, Y. Sustainable bioenergy solutions to Enable Development in Low-and Middle-Income Countries Beyond Technology and Energy Access. *Biomass and Bioenergy*. 2020. 143: 105876.

14. Gerssen-Gondelach, S. J., Saygin, D., Wicke, B., Patel, M. K. and Faaij, A. P. C. Competing Uses of Biomass: Assessment and Comparison of the Performance of Bio-Based Heat, Power, Fuels and Materials. *Renewable and Sustainable Energy Reviews*. 2014. 40: 964-998.

15. Daioglou, V., Rose, S. K., Bauer, N., Kitous, A., Muratori, M., Sano, F., Fujimori, S., Gidden, M. J., Kato, E., Keramidas, K. and Klein, D. Bioenergy technologies in long-run climate change mitigation: results from the EMF-33 study. *Climatic Change*. 2020. 163: 1603-1620.

16. Lin, B. and He, J. Learning Curves for Harnessing Biomass Power: What Could Explain The Reduction of its Cost During the Expansion of China?. *Renewable Energy*. 2016. 99: 280-288.

17. Riahi, K., Kriegler, E., Johnson, N., Bertram, C., Den Elzen, M., Eom, J., Schaeffer, M., Edmonds, J., Isaac, M., Krey, V. and Longden, T. Locked into Copenhagen Pledges—Implications of Short-Term Emission Targets for the Cost and Feasibility of Long-Term Climate Goals. *Technological Forecasting and Social Change*. 2015. 90: 8-23.

18. Fuss, S., Lamb, W. F., Callaghan, M. W., Hilaire, J., Creutzig, F., Amann, T., Beringer, T., de Oliveira Garcia, W., Hartmann, J., Khanna, T. and Luderer, G. Negative Emissions—Part 2: Costs, Potentials and Side Effects. *Environmental Research Letters*. 2018. 13: 063002.

19. Cristobal, J., Matos, C., Aurambout, J., Manfredi, S. and Kavalov, B. Environmental Sustainability Assessment of Bioeconomy Value Chains. *Biomass and Bioenergy*. 2016. 89: 159-171.

20. Kalt, G., Baumann, M., Lauk, C., Kastner, T., Kranzl, L., Schipfer, F., Lexer, M., Rammer, W., Schaumberger, A. and Schriefl, E. Transformation Scenarios Towards a Low-Carbon Bioeconomy in Austria. *Energy Strategy Reviews*. 2016. 13: 125-133.

21. Durusut, E., Tahir, F., Foster S., Dineen, D. and Clancy, M. BioHEAT: A Policy Decision Support Tool in Ireland’s Bioenergy and Heat Sectors. *Applied Energy*. 2018. 213: 306-321.

22. Clancy, J. M., Curtis, J. and Ó’Gallachóir, B. Modelling National Policy Making to Promote Bioenergy in Heat, Transport and Electricity to 2030 – Interactions, Impacts and Conflicts. *Energy Policy*. 2018. 123: 579-593.

23. Vasile, A. J., Andreea, I. R., Popescu, G. H., Elvira, N. and Marian, Z. Implications of Agricultural Bioenergy Crop Production and Prices in Changing the Land Use Paradigm – The Case of Romania. *Land Use Policy*. 2016. 50: 399-407.

24. Welfle, A. Balancing Growing Global Bioenergy Resource Demands – Brazil's Biomass Potential and the Availability of Resource for Trade. *Biomass and Bioenergy*. 2017. 105: 83-95.

25. Wightman, J. L., Ahmed, Z. U., Volk, T. A., Castellano, P. J., Peters, C. J., DeGloria, S. D., Duxbury, J. M. and Woodbury, P. B. Assessing Sustainable Bioenergy Feedstock Production Potential by Integrated Geospatial Analysis of Land Use and Land Quality. *BioEnergy Research*. 2015. 8(4): 1671-1680.
26. Townsend, T. J., Sparkes, D. L., Ramsden, S. J., Glithero, N. J. and Wilson, P. Wheat Straw Availability for Bioenergy in England. *Energy Policy*. 2018. 122: 349-357.
27. Paulo, H., Azcue, X., Barbosa-Póvoa, A. P. and Relvas, S. Supply Chain Optimization of Residual Forestry Biomass for Bioenergy Production: The Case Study of Portugal. *Biomass and Bioenergy*. 2015. 83: 245-256.
28. Shu, K., Schneider, U. A. and Scheffran, J. Optimizing the Bioenergy Industry Infrastructure: Transportation Networks and Bioenergy Plant Locations. *Applied Energy*. 2017. 192: 247-261.
29. Flodén, J. and Williamsson, J. Business Models for Sustainable Biofuel Transport: The Potential for Intermodal Transport. *Journal of Cleaner Production*. 2016. 113: 426-437.
30. Poudel, S. R., Marufuzzaman, M. and Bian, L. A. Hybrid Decomposition Algorithm for Designing a Multi-Modal Transportation Network under Biomass Supply Uncertainty. *Transportation Research Part E: Logistics and Transportation Review*. 2016. 94: 1-25.
31. de Jong, S., Hoefnagels, R., Wetterlund, E., Pettersson, K., Faaij, A. and Junginger, M. Cost Optimization of Biofuel Production–The Impact of Scale, Integration, Transport and Supply Chain Configurations. *Applied Energy*. 2017. 195: 1055-1070.
32. De Meyer, A., Cattrysse, D. and Van Orshoven, J. A Generic Mathematical Model to Optimise Strategic and Tactical Decisions in Biomass-Based Supply Chains (OPTIMASS). *European Journal of Operational Research*. 2015. 245(1): 247-264.
33. Heuberger, C. F., Bains, P. K. and Mac Dowell, N. The EV-olution of the Power System: A Spatio-Temporal Optimisation Model to Investigate the Impact of Electric Vehicle Deployment. *Applied Energy*. 2020. 257: 113715.

34. Pettersson, K., Wetterlund, E., Athanassiadis, D., Lundmark, R., Ehn, C., Lundgren, J. and Berglin, N. Integration of Next-Generation Biofuel Production in the Swedish Forest Industry - A Geographically Explicit Approach. *Applied Energy*. 2015. 154: 317-332.
35. Hiloidhari, M., Baruah, D. C, Singh, A., Kataki, S., Medhi, K., Kumari, S., Ramachandra, T. V., Jenkins, B. M. and Thakur, I. S. Emerging Role of Geographical Information System (GIS), Life Cycle Assessment (LCA) and Spatial LCA (GIS-LCA) in Sustainable Bioenergy Planning. *Bioresource Technology*. 2017. 242: 218-226.
36. Leduc, S. Lundgren, J., Franklin, O. and Dotzauer, E. Location of a Biomass Based Methanol Production Plant: A Dynamic Problem in Northern Sweden. *Applied Energy*. 2010. 87(1): 68-75.
37. Johnson, N., Parker, N. and Ogden, J. How Negative can Biofuels with CCS Take Us and at What Cost? Refining the Economic Potential of Biofuel Production with CCS using Spatially-Explicit Modeling. *Energy Procedia*. 2014. 63: 6770-6791.
38. Samsatli, S., Samsatli, N. J. and Shah, N. BVCM: A Comprehensive and Flexible Toolkit for Whole System Biomass Value Chain Analysis and Optimisation – Mathematical Formulation. *Applied Energy*. 2015. 147: 131-160.
39. Leila, M., Whalen, J. and Bergthorson, J. Strategic Spatial and Temporal Design of Renewable Diesel and Biojet Fuel Supply Chains: Case Study of California, USA. *Energy*. 2018. 156: 181-195.
40. Patrizio, P., Leduc, S., Kraxner, F., Fuss, S., Kindermann G., Mesfun S., Spokas K. and Mendoza Ponce, A. Reducing US Coal Emissions can Boost Employment. *Joule*. 2018. 2(12): 2633-2648.
41. Truong, A. H., Patrizio, P., Leduc, S., Kraxner, F. and Ha-Duong, M. Reducing Emissions of the Fast Growing Vietnamese Coal Sector: The Chances Offered by Biomass Co-Firing. *Journal of Cleaner Production*. 2019. 215: 1301-1311.
42. Zhang, D., Bui, M., Fajardy, M., Patrizio, P., Kraxner, F., Mac Dowell, N. Unlocking the Potential of BECCS with Indigenous Sources of Biomass at a National Scale. *Sustainable Energy & Fuels*. 2020. 4(1): 226-253.

43. Fajardy, M. and Mac Dowell, N. Recognizing the Value of Collaboration in Delivering Carbon Dioxide Removal. *One Earth*. 2020. 3(2): 214-225.

44. Börjesson, M., Athanassiadis, D., Lundmark, R., Ahlgren, E. O. Bioenergy Futures in Sweden–System Effects of CO2 Reduction and Fossil Fuel Phase-Out Policies. *GCB Bioenergy*. 2015. 7(5): 1118-1135.

45. Thrän, D., Schaldach, R., Millinger, M., Wolf, V., Arendt, O., Ponitka, J., Gärtner, S., Rettenmaier, N., Hennenberg, K. and Schüngel, J. The MILESTONES Modeling Framework: An Integrated Analysis of National Bioenergy Strategies and their Global Environmental Impacts. *Environmental Modelling & Software*. 2016. 86, 14-29.

46. Pan, X., Chen, W., Wang, L., Lin, L. and Li, N. The Role of Biomass in China's Long-Term Mitigation toward the Paris Climate Goals. *Environmental Research Letters*. 2018. 13(12): 124028.

47. UNFCCC. *FCCC/CP/2015/L.9/Rev.1*. Paris, France: United Nations Framework Convention on Climate Change. 2015.

48. UNFCCC. INDCs as Communicated by Parties [Internet]. Paris, France: *United Nations Framework Convention on Climate Change*; 2015 [updated 2017; cited 2019 November 12]. Available from: http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx.

49. Hof, A. F., den Elzen, M. G., Admiraal, A., Roelfsema, M., Gernaat, D. E. and Van Vuuren, D. P. Global and Regional Abatement Costs of Nationally Determined Contributions (NDCs) and of Enhanced Action to levels Well Below 2 °C and 1.5 °C. *Environmental Science & Policy*. 2017. 71: 30-40.

50. Rogelj, J., den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., Schaeffer, R., Sha, F., Riahi, K. and Meinshausen, M. Paris Agreement Climate Proposals Need a Boost to Keep Warming Well Below 2 °C. *Nature*. 2016. 534(7609): 631-639.

51. IEA. *Southeast Asia Energy Outlook – World Energy Outlook Special Report*. Paris, France: International Energy Agency. 2015.

52. KeTTHA. *Green Technology Master Plan Malaysia 2017-2030*. Putrajaya, Malaysia: Ministry of Energy, Green Technology and Water. 2017.

53. MESTECC. *Third National Communication and Second Biennial Update Report to the UNFCCC*. Putrajaya, Malaysia: Ministry of Energy, Science, Technology, Environment and Climate Change. 2018.

54. MESTECC. *MESTECC's Initiatives*. Putrajaya, Malaysia: Ministry of Energy, Science, Technology, Environment and Climate Change. 2019.

55. MITI. *Malaysia Committed to Role as Biofuel Technology Player*. Kuala Lumpur, Malaysia: Ministry of International Trade and Industry. 2019.

56. IEA. *World Energy Balance 2020*. France: International Energy Agency. 2020.

57. Wahab, A. G. *Biofuels Annual – Malaysia*. Washington, DC: United States Department of Agriculture. 2019.

58. Pang, S. Advances in thermochemical conversion of woody biomass to energy, fuels and chemicals. *Biotechnology Advances*. 2019. 37(4): 589-597.

59. Yi, Q., Zhao, Y., Huang, Y., Wei, G., Hao, Y., Feng, J., Mohamed, U., Pourkashanian, M., Nimmo, W. and Li, W. Life Cycle Energy-Economic-CO_2 Emissions Evaluation of Biomass/Coal, with and without CO_2 Capture and Storage, in a Pulverized Fuel Combustion Power Plant in the United Kingdom. *Applied Energy*. 2018. 225: 258-272.

60. Umar, M. S., Jennings, P. and Urmee, T. Sustainable Electricity Generation from Oil Palm Biomass Wastes in Malaysia: An Industry Survey. *Energy*. 2014. 67: 496-505.

61. Kong, S. H., Loh, S. K., Bachmann, R. T., Rahim, S. A. and Salimon, J. Biochar from Oil Palm Biomass: A Review of its Potential and Challenges. *Renewable and Sustainable Energy Reviews*. 2014. 39: 729-739.

62. Yue, D. and You, F. Biomass and Biofuel Supply Chain Modeling and Optimization. In: Holm-Nielsen, J.B. and Ehimen, E. A. eds. *Biomass Supply Chains for Bioenergy and Biorefining*. Cambridge: Woodhead Publishing. 149-166; 2016.

63. Azam, M., Othman, J., Begum, R. A., Abdullah, S. M. S. and Nor, N. G. M. Energy Consumption and Emission Projection for the Road Transport Sector in Malaysia: An Application of the LEAP Model. *Environment, Development and Sustainability*. 2016. 18(4): 1027-1047.

64. Muis, Z. A., Ho, W. S., Hashim, H., Lee, M. Y. and Ramli, A. F. Sustainable Multi-Period Electricity Planning for Iskandar Malaysia. *Clean Technologies and Environmental Policy*. 2016. 18(8): 2467-2478.

65. Haiges, R., Wang, Y. D., Ghoshray, A. and Roskilly, A. P. Optimization of Malaysia's Power Generation Mix to Meet the Electricity Demand by 2050. *Energy Procedia*. 2017. 142: 2844-2851.

66. MPOB. Economics and Industry Development Division [Internet]. Selangor, Malaysia: *Malaysian Palm Oil Board*; 2021 [updated 2021; cited 2021 June 09]. Available from: http://bepi.mpob.gov.my/.

67. ArcMap (version 10.3). Software. Redlands, CA: *Esri Inc*. 2014.

68. GAMS (Generic Algebraic Modeling Software) (version 24.6.1). Software. United States: *GAMS Development Corporation*. 2010.

69. Microsoft Excel (version 2016). Software. United States: *Microsoft Corporation*. 2016.

70. Van Rossum, G. and Drake, F. L. Python 3 Reference Manual. Scotts Valley, CA: *CreateSpace*. 2009.

71. IEA. Data and Statistics [Internet]. Paris, France: *International Energy Agency*; 2020. [Updated 2020; cited 2021 January 03]. Available from: https://www.iea.org/data-and-statistics/.

72. Brauers, H., Oei, P. Y. and Walk, P. Comparing Coal Phase-Out Pathways: The United Kingdom's and Germany's Diverging Transitions, *Environmental Innovation and Societal Transitions*. 2020. 37: 238-253.

73. Rinscheid, A. and Wüstenhagen, R. Germany's Decision to Phase Out Coal by 2038 Lags Behind Citizens' Timing Preferences. *Nature Energy*. 2019. 4(10): 856-863.

74. Pilpola, S. and Lund, P. D. Effect of Major Policy Disruptions in Energy System Transition: Case Finland. *Energy Policy*. 2018. 116, 323-336.

75. Roni, M. S., Chowdhury, S., Mamun, S., Marufuzzaman, M., Lein, W., Johnson, S. Biomass Co-firing Technology with Policies, Challenges, and Opportunities: A Global Review. *Renewable and Sustainable Energy Reviews*. 2017. 78: 1089-1101.

76. Khorshidi, Z., Ho, M. T. and Wiley, D. E. The Impact of Biomass Quality and Quantity on the Performance and Economics of Co-firing Plants with and without CO2 capture. *International Journal of Greenhouse Gas Control*. 2014. 21: 191-202.

77. IEA-ETSAP-IRENA. *Technology-Policy Brief E21 – Biomass Co-firing in Coal Power Plants*. Paris, France: IEA-ETSAP Energy Technology Systems Analysis. 2013.

78. Verma, M., Loha, C., Sinha, A. N. and Chatterjee, P. K. Drying of Biomass for Utilising in Co-Firing with Coal and its Impact on Environment–A Review. *Renewable and Sustainable Energy Reviews*. 2017. 71: 732-741.

79. Bertrand, V., Dequiedt, B. and Le Cadre, E. Biomass for Electricity in the EU-27: Potential Demand, CO2 Abatements and Breakeven Prices for Co-firing. *Energy Policy*. 2014. 73: 631-644.

80. Sahu, S. G., Chakraborty, N. and Sarkar, P. Coal–Biomass Co-combustion: An Overview. *Renewable and Sustainable Energy Reviews*. 2014. 39: 575-586.

81. Bhuiyan, A. A., Blicblau, A. S., Islam, A. S. and Naser, J. A Review on Thermo-Chemical Characteristics of Coal/Biomass Co-firing in Industrial Furnace. *Journal of the Energy Institute*. 2018. 91(1): 1-18.

82. Gil, M. V. and Rubiera, F. Coal and Biomass Cofiring: Fundamentals and Future Trends. In: Suárez-Ruiz, I., Antonia Diez, M. and Rubiera, F. eds. *New Trends in Coal Conversion*. Cambridge: Woodhead Publishing. 117-140; 2019.

83. Karampinis, E., Grammelis, P., Agraniotis, M., Violidakis, I. and Kakaras, E. Co-firing of Biomass with Coal in Thermal Power Plants: Technology Schemes, Impacts, and Future Perspectives. *Wiley Interdisciplinary Reviews: Energy and Environment*. 2014. 3(4): 384-399.

84. Agbor, E., Zhang, X. and Kumar, A. A review of Biomass Co-Firing in North America. *Renewable and Sustainable Energy Reviews*. 2014. 40: 930-943.

85. Mun, T. Y., Tumsa, T. Z., Lee, U. and Yang, W. Performance Evaluation of Co-Firing Various Kinds of Biomass with Low Rank Coals in a 500 MWe Coal-Fired Power Plant. *Energy*. 2016. 115: 954-962.

86. Pérez-Fortes, M., Laínez-Aguirre, J. M., Bojarski, A. D. and Puigjaner, L. Optimization of Pre-Treatment Selection for the Use of Woody Waste in Co-combustion Plants. *Chemical Engineering Research and Design*. 2014. 92(8): 1539-1562.

87. Loh, S. K. The Potential of the Malaysian Oil Palm Biomass as a Renewable Energy Source. *Energy Conversion and Management*. 2017. 141: 285-298.

88. Luk, H. T., Lam, T. Y. G., Oyedun, A. O., Gebreegziabher, T. and Hui, C. W. Drying of Biomass for Power Generation: A Case Study on Power Generation from Empty Fruit Bunch. *Energy*. 2013. 63: 205-215.
89. Gebreegziabher, T., Oyedun, A. O. and Hui, C. W. Optimum Biomass Drying for Combustion–A Modeling Approach. *Energy*. 2013. 53: 67-73.
90. Chai, L. and Saffron, C. M. Comparing Pelletization and Torrefaction Depots: Optimization of Depot Capacity and Biomass Moisture to Determine the Minimum Production Cost. *Applied Energy*. 2016. 163: 387-395.
91. Wolfsmayr, U. J. and Rauch, P. The Primary Forest Fuel Supply Chain: A Literature Review. *Biomass and Bioenergy*. 2014. 60, 203-221.
92. García, R., Gil, M. V., Rubiera, F. and Pevida, C. Pelletization of Wood and Alternative Residual Biomass Blends for Producing Industrial Quality Pellets. *Fuel*. 2019. 251, 739-753.
93. International Organization for Standardization. *Solid Biofuels — Fuel Specifications and Classes — Part 1: General Requirements*. Geneva, Switzerland, ISO 17225-1:2014. 2014.
94. International Organization for Standardization. *Solid Biofuels — Fuel Specifications and Classes — Part 4: Graded Wood Chips*. Geneva, Switzerland, ISO 17225-4:2014. 2014.
95. International Organization for Standardization. *Solid Biofuels — Fuel Specifications and Classes — Part 2: Graded Wood Pellets*. Geneva, Switzerland, ISO 17225-2:2014. 2014.
96. International Organization for Standardization. Solid Biofuels — Fuel Specifications and Classes — Part 6: Graded Non-Woody Pellets. Geneva, Switzerland, ISO 17225-6:2014. 2014.
97. International Organization for Standardization. *Solid Biofuels — Fuel Specifications and Classes — Part 8: Graded Thermally Treated and Densified Biomass Fuels*. Geneva, Switzerland, ISO 17225-8:2016. 2016.
98. ASTM International. *Standard Classification of Coals by Rank*. West Conshohocken, PA, ASTM D388-99. 1999.
99. Rokni, E., Ren, X., Panahi, A. and Levendis, Y. A. Emissions of SO2, NOx, CO2, and HCl from Co-firing of Coals with Raw and Torrefied Biomass Fuels. *Fuel*. 2018. 211: 363-374.

100. Adams, P. W. R., Shirley, J. E. J. and McManus, M. C. Comparative Cradle-To-Gate Life Cycle Assessment of Wood Pellet Production with Torrefaction. *Applied Energy*. 2015. 138, 367-380.

101. Budde, P. K., Megha, R., Patel, R. and Pandey, J. Investigating Effects of Temperature on Fuel Properties of Torrefied Biomass for Bio-Energy Systems. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*. 2019. 41(9): 1140-1148.

102. Rentizelas, A. A. and Li, J. Techno-Economic and Carbon Emissions Analysis of Biomass Torrefaction Downstream in International Bioenergy Supply Chains for Co-firing. *Energy*. 2016. 114, 129-142.

103. Mauro, C., Rentizelas, A. A. and Chinese, D. International vs. Domestic Bioenergy Supply Chains for Co-Firing Plants: The Role of Pre-treatment Technologies. *Renewable Energy*. 2018. 119: 712-730.

104. Ehrig, R and Behrendt, F. Co-firing of Imported Wood Pellets–An Option to Efficiently Save CO2 Emissions in Europe?. *Energy Policy*. 2013. 59: 283-300.

105. Miedema, J. H., Benders, R. M., Moll, H. C. and Pierie, F. Renew, Reduce or Become More Efficient? The Climate Contribution of Biomass Co-Combustion in a Coal-Fired Power Plant. *Applied Energy*. 2017. 187: 873-885.

106. Tsalidis, G. A., Joshi, Y., Korevaar, G. and de Jong, W. Life Cycle Assessment of Direct Co-firing of Torrefied and/or Pelletised Woody Biomass with Coal in The Netherlands. *Journal of Cleaner Production*. 2014. 81: 168-177.

107. Morrison, B. and Golden, J. S. Life Cycle Assessment of Co-firing Coal and Wood Pellets in the Southeastern United States. *Journal of Cleaner Production*. 2017. 150: 188-196.

108. Kommalapati, R. R., Hossan, I., Botlaguduru, V. S. V., Du, H. and Huque, Z. Life Cycle Environmental Impact of Biomass Co-Firing with Coal at a Power Plant in the Greater Houston Area. *Sustainability*. 2018. 10(7): 2193.

109. Wang, R., Chang, S., Cui, X., Li, J., Ma, L., Kumar, A., Nie, Y. and Cai, W. Retrofitting Coal-Fired Power Plants with Biomass Co-Firing and Carbon Capture and Storage for Net Zero Carbon Emission: A Plant-By-Plant Assessment Framework. *GCB Bioenergy*. 2021. 13(1): 143-160.

110. Clare, A., Gou, Y.Q., Barnes, A., Shackley, S., Smallman, T.L., Wang, W., Jiang, D. and Li, J. Should China Subsidize Cofiring to Meet its 2020 Bioenergy Target? A Spatio-Techno-Economic Analysis. *GCB Bioenergy*. 2016. 8(3): 550-560.

111. Rodrigues, A., Gonçalves, A. B., Casquilho, M. and Gomes, A. A. A GIS-Based Evaluation of the Potential of Woody Short Rotation Coppice (SRC) in Portugal Aiming at Co-firing and Decentralized Co-generation. *Biomass and Bioenergy*. 2020. 137: 105554.

112. Li, J., Wang, R., Li, H., Nie, Y., Song, X., Li, M., Shi, M., Zheng, X., Cai, W. and Wang, C. Unit-Level Cost-Benefit Analysis for Coal Power Plants Retrofitted with Biomass Co-firing at a National Level by Combined GIS and Life Cycle Assessment. *Applied Energy*. 2021. 285: 116494.

113. Nunes, L. J. R., Causer, T. P. and Ciolkosz, D. Biomass for Energy: A Review on Supply Chain Management Models. *Renewable and Sustainable Energy Reviews*. 2020. 120: 109658.

114. Akgul, O., Mac Dowell, N., Papageorgiou, L. G. and Shah, N. A Mixed Integer Nonlinear Programming (MINLP) Supply Chain Optimisation Framework for Carbon Negative Electricity Generation using Biomass to Energy with CCS (BECCS) in the UK. *International Journal of Greenhouse Gas Control*. 2014. 28, 189-202.

115. Roni, M. S., Eksioglu, S. D., Searcy, E. and Jha, K. A Supply Chain Network Design Model for Biomass Co-firing in Coal-Fired Power Plants. *Transportation Research Part E: Logistics and Transportation Review*. 2014. 61: 115-134.

116. Aranguren, M. F., Castillo-Villar, K. K., Aboytes-Ojeda, M. and Giacomoni, M. H. Simulation-Optimization Approach for the Logistics Network Design of Biomass Co-firing with Coal at Power Plants. *Sustainability*. 2018. 10: 4299.

117. Ko, S. and Lautala, P. Optimal Level of Woody Biomass Co-firing with Coal Power Plant Considering Advanced Feedstock Logistics System. *Agriculture*. 2018. 8(6): 74.

118. San Juan, J. L. G., Aviso, K. B., Tan, R. R. and Sy, C. L. A Multi-Objective Optimization Model for the Design of Biomass Co-Firing Networks Integrating Feedstock Quality Considerations. *Energies*. 2019. 12(12): 2252.

119. Rösch, C., Jörissen, J., Skarka, J. and Knapp, M. Strategies to Reduce Land Use Competition and Increasing the Share of Biomass in the German Energy Supply. *18th European Biomass Conference and Exhibition*. May 3-7, 2010. Lyon, France: JRC-IE. 2010. 34-39.

120. Daioglou, V., Doelman, J. C., Wicke, B., Faaij, A. and van Vuuren, D. P. Integrated Assessment of Biomass Supply and Demand in Climate Change Mitigation Scenarios. *Global Environmental Change.* 2019. 54: 88-101.

121. Deng, Y. Y., Koper, M., Haigh, M. and Dornburg, V. Country-Level Assessment of Long-Term Global Bioenergy Potential. *Biomass and Bioenergy*. 2015. 74: 253-267.

122. Sharma, B., Ingalls, R. G., Jones, C. L. and Khanchi, A. Biomass Supply Chain Design and Analysis: Basis, Overview, Modeling, Challenges, and Future. *Renewable and Sustainable Energy Reviews*. 2013. 24: 608-627.

123. Yue, D., You, F. and Snyder, S. W. Biomass-to-Bioenergy and Biofuel Supply Chain Optimization: Overview, Key Issues and Challenges. *Computers & Chemical Engineering*. 2014. 66: 36-56.

124. Thrän, D., Billig, E., Brosowski, A., Klemm, M., Seitz, S. B. and Witt, J. Bioenergy Carriers–From Smoothly Treated Biomass Towards Solid and Gaseous Biofuels. *Chemie Ingenieur Technik*. 2018. 90(1-2): 68-84.

125. Fajardy, M. C. Developing a framework for the optimal deployment of negative emissions technologies. Ph.D. Thesis. Imperial College London; 2019.

126. Lam, M. K., Loy, A. C. M., Yusup, S. and Lee, K. T. Biohydrogen Production from Algae. In: Pandey, A., Mohan, S. V., Chang, J. S., Hallenbeck, P. C. and Larroche, C. eds. *Biomass, Biofuels and Biochemical: Biohydrogen*. Amsterdam, Netherlands: Elsevier. 219-245; 2019.

127. Achinas, S., Achinas, V. and Euverink, G. J. W. Microbiology and Biochemistry of Anaerobic Digesters: An Overview. In: Singh, L., Yousuf, A. and Madhab, D. eds. *Bioreactors: Sustainable Design and Industrial Applications in Mitigation of GHG Emissions*. 17-26; 2020.

128. Sankaran, R., Show, P. L., Nagarajan, D. and Chang, J. S. Exploitation and Biorefinery of Microalgae. In: Bhaskar, T., Pandey, A., Mohan, S. V., Lee, D. J. and Khanal, S. K. eds. *Waste Biorefinery: Potential and Perspectives*. Amsterdam, Netherlands: Elsevier. 571-601; 2018.

129. Zhang, Y., Cui, Y., Chen, P., Liu, S., Zhou, N., Ding, K., Fan, L., Peng, P., Min, M., Cheng, Y. and Wang, Y. Gasification Technologies and Their Energy Potentials. In: Taherzadeh, M. J., Bolton, K., Wong, J. and Pandey, A. eds. *Sustainable Resource Recovery and Zero Waste Approaches*. Amsterdam, Netherlands: Elsevier. 193-206; 2019.

130. Mumtaz, M. W., Adnan, A., Mukhtar, H., Rashid, U. and Danish, M. Biodiesel Production Through Chemical and Biochemical Transesterification: Trends, Technicalities, and Future Perspectives. In: Rasul, M. G., Azad, A. K. and Sharma, S. C. eds. *Clean Energy for Sustainable Development: Comparisons and Contrasts of New Approaches*. USA: Academic Press. 465-485; 2017.

131. Quintero, J. A., Montoya, M. I., Sánchez, O. J., Giraldo, O. H. and Cardona, C. A. Fuel Ethanol Production from Sugarcane and Corn: Comparative Analysis for a Colombian Case. *Energy*. 2008. 33(3): 385-399.

132. Quintero, J. A., Moncada, J. and Cardona, C. A. Techno-Economic Analysis of Bioethanol Production from Lignocellulosic Residues in Colombia: A Process Simulation Approach. *Bioresource Technology*. 2013. 139: 300-307.

133. Popp, J., Lakner, Z., Harangi-Rakos, M. and Fari, M. The Effect of Bioenergy Expansion: Food, Energy, and Environment. *Renewable and Sustainable Energy Reviews*. 2014. 32: 559-578.

134. Keller, V., Benjamin, L., Jeffrey, E., Taco, N., Kevin, P. W., Iman, M., Bryson, R., Peter, W. and Andrew, R. Coal-to-Biomass Retrofit in Alberta–Value of Forest Residue Bioenergy in the Electricity System. *Renewable Energy*. 2018. 125: 373-383.

135. Cutz, L., Berndes, G. and Johnsson, F. A Techno-Economic Assessment of Biomass Co-Firing in Czech Republic, France, Germany and Poland. *Biofuels, Bioproducts and Biorefining*. 2019. 13(5): 1289-1305.

136. Knapp S., Güldemund A., Weyand S. and Schebek L. Evaluation of Co-firing as a Cost-Effective Short-Term Sustainable CO_2 Mitigation Strategy in Germany. *Energy, Sustainability and Society*. 2019. 9(1): 32.

137. Bhave, A., Taylor, R.H., Fennell, P., Livingston, W.R., Shah, N., Mac Dowell, N., Dennis, J., Kraft, M., Pourkashanian, M., Insa, M. and Jones, J. Screening and Techno-Economic Assessment of Biomass-Based Power Generation with CCS Technologies to Meet 2050 CO_2 targets. *Applied Energy*. 2017. 190: 481-489.

138. Bui, M., Zhang, D., Fajardy, M. and Mac Dowell, N. Delivering Carbon Negative Electricity, Heat and Hydrogen with BECCS–Comparing the Options. *International Journal of Hydrogen Energy*. 2021. 46: 15298-15321.
139. Xu, Y., Yang, K., Zhou, J. and Zhao, G. Coal-Biomass Co-Firing Power Generation Technology: Current Status, Challenges and Policy Implications. *Sustainability*. 2020. 12(9): 3692.
140. Yang, B., Wei, Y. M., Liu, L.C., Hou, Y. B., Zhang, K., Yang, L. and Feng, Y. Life Cycle Cost Assessment of Biomass Co-Firing Power Plants with CO2 Capture and Storage Considering Multiple Incentives. *Energy Economics*. 2021. 96: 105173.
141. Lu, Y., Khan, Z. A., Alvarez-Alvarado, M. S., Zhang, Y., Huang, Z. and Imran, M. A Critical Review of Sustainable Energy Policies for the Promotion of Renewable Energy Sources. *Sustainability*. 2020. 12(12): 5078.
142. Sun, K., Xiao, H., Liu, S., You, S., Yang, F., Dong, Y., Wang, W. and Liu, Y. A Review of Clean Electricity Policies—From Countries to Utilities. *Sustainability*. 2020. 12(19): 7946.
143. Soltani, S., Mahmoudi, S. M. S., Yari, M., Morosuk, T., Rosen, M. A. and Zare, V. A Comparative Exergoeconomic Analysis of Two Biomass and Co-firing Combined Power Plants. *Energy Conversion and Management*. 2013. 76: 83-91.
144. Malek, A. A., Hasanuzzaman, M., Abd Rahim, N. and Al Turki, Y. A. Techno-Economic Analysis and Environmental Impact Assessment of a 10 MW Biomass-Based Power Plant in Malaysia. *Journal of Cleaner Production*. 2017. 141: 502-513.
145. Schipfer F. and Kranzl L. Techno-Economic Evaluation of Biomass-to-End-Use Chains based on Densified Bioenergy Carriers (dBECs). *Applied Energy*. 2019. 239: 715-724.
146. Zhou, H. L., Silveira, S., Tang, B. J. and Qu, S. Optimal Timing for Carbon Capture Retrofitting in Biomass-Coal Combined Heat and Power Plants in China. *Journal of Cleaner Production*. 2021. 293: 126134.
147. Roni, M. S., Thompson, D. N. and Hartley, D. S. Distributed Biomass Supply Chain Cost Optimization to Evaluate Multiple Feedstocks for a Biorefinery. *Applied Energy*. 2019. 254: 113660.

148. Haji Esmaeili, S. A., Szmerekovsky, J., Sobhani, A., Dybing, A. and Peterson, T. O. Sustainable Biomass Supply Chain Network Design with Biomass Switching Incentives for First-Generation Bioethanol Producers. *Energy Policy*. 2020. 138: 111222.

149. He-Lambert, L., English, B. C., Lambert, D. M., Shylo, O., Larson, J. A., Yu, T. E. and Wilson, B. Determining a Geographic High Resolution Supply Chain Network for a Large Scale Biofuel Industry. *Applied Energy*. 2018. 218: 266-281.

150. Ng, R. T., Kurniawan, D., Wang, H., Mariska, B., Wu, W. and Maravelias, C. T. Integrated Framework for Designing Spatially Explicit Biofuel Supply Chains. *Applied Energy*. 2018. 216: 116-131.

151. Harahap, F., Leduc, S., Mesfun, S., Khatiwada, D., Kraxner, F. and Silveira, S. Opportunities to Optimize the Palm Oil Supply Chain in Sumatra, Indonesia. *Energies*. 2019. 12(3): 420.

152. Harahap, F., Leduc, S., Mesfun, S., Khatiwada, D., Kraxner, F. and Silveira, S. Meeting the Bioenergy Targets from Palm Oil Based Biorefineries: An Optimal Configuration in Indonesia. Applied Energy. 2020. 278: 115749.

153. Mandova, H., Leduc, S., Wang, C., Wetterlund, E., Patrizio, P., Gale, W. and Kraxner, F. Possibilities for CO_2 Emission Reduction Using Biomass in European Integrated Steel Plants. *Biomass and Bioenergy*. 2018. 115: 231-243.

154. Mesfun, S., Leduc, S., Patrizio, P., Wetterlund, E., Mendoza-Ponce, A., Lammens, T., Staritsky, I., Elbersen, B., Lundgren, J. and Kraxner F. Spatio-Temporal Assessment of Integrating Intermittent Electricity in the EU and Western Balkans Power Sector under Ambitious CO_2 Emission Policies. *Energy*. 2018. 164: 676-693.

155. Mandova, H., Patrizio, P., Leduc, S., Kjärstad, J., Wang, C., Wetterlund, E., Kraxner, F. and Gale, W. Achieving Carbon-Neutral Iron and Steelmaking in Europe through the Deployment of Bioenergy with Carbon Capture and Storage. *Journal of Cleaner Production*. 2019. 218: 118-129.

156. Ascenso, L., d'Amore, F., Carvalho, A. and Bezzo, F. Assessing Multiple Biomass-Feedstock in the Optimization of Power and Fuel Supply Chains for Sustainable Mobility. *Chemical Engineering Research and Design*. 2018. 131; 127-143.

157. Chiew, Y. L., Iwata, T. and Shimada, S. System Analysis for Effective Use of Palm Oil Waste as Energy Resources. *Biomass and Bioenergy*. 2011. 35(7): 2925-2935.

158. Lam, H. L., Ng, W. P., Ng, R. T., Ng, E. H., Aziz, M. K. A. and Ng, D. K. Green Strategy for Sustainable Waste-to-Energy Supply Chain. *Energy*. 2013. 57: 4-16.

159. How, B. S., Tan, K. Y. and Lam, H. L. Transportation Decision Tool for Optimisation of Integrated Biomass Flow with Vehicle Capacity Constraints. *Journal of Cleaner Production*. 2016. 136: 197-223.

160. Abdulrazik, A., Elsholkami, M., Elkamel, A. and Simon, L. Multi-Products Productions from Malaysian Oil Palm Empty Fruit Bunch (EFB): Analyzing Economic Potentials from the Optimal Biomass Supply Chain. *Journal of Cleaner Production*. 2017. 168: 131-148.

161. Rubinsin, N.J., Daud, W. R. W., Kamarudin, S. K., Masdar, M. S., Rosli, M. I., Samsatli, S., Tapia, J. F., Ghani, W. A. W. A. K. and Lim, K. L. Optimization of Oil Palm Empty Fruit Bunches Value Chain in Peninsular Malaysia. *Food and Bioproducts Processing*. 2020. 119: 179-194.

162. Rubinsin, N. J., Daud, W. R. W., Kamarudin, S. K., Masdar, M. S., Rosli, M. I., Samsatli, S., Tapia, J. F. D., Ghani, W. A. W. A. K., Hasan, A. and Lim, K. L. Modelling and Optimisation of Oil Palm Biomass Value Chains and the Environment–Food–Energy–Water Nexus in Peninsular Malaysia. *Biomass and Bioenergy*. 2021. 144: 105912.

163. Tapia, J. F. D. and Samsatli, S. Integrating Fuzzy Analytic Hierarchy Process into a Multi-Objective Optimisation Model for Planning Sustainable Oil Palm Value Chains. *Food and Bioproducts Processing*. 2020. 119: 48-74.

164. Theo, W. L., Lim, J. S., Ho, W. S., Hashim, H., Lee, C. T. and Muis, Z. A. Optimisation of Oil Palm Biomass and Palm Oil Mill Effluent (POME) Utilisation Pathway for Palm Oil Mill Cluster with Consideration of BioCNG Distribution Network. *Energy*. 2017. 121: 865-883.

165. Lee, M. K., Hashim, H., Lim, J. S. and Taib, M. R. Spatial Planning and Optimisation for Virtual Distribution of BioCNG Derived from Palm Oil Mill Effluent to Meet Industrial Energy Demand. *Renewable Energy*. 2019. 141: 526-540.

166. Lee, M. K., Hashim, H., Ho, W. S., Ab Muis, Z., Yunus, N. A. and Xu, H. Integrated Spatial and Pinch Analysis of Optimal Industrial Energy Supply Mix with Consideration of BioCNG Derived from Palm Oil Mill Effluent. *Energy*. 2020. 209: 118349.

167. Tan, S. T., Hashim, H., Rashid, A. H. A., Lim, J. S., Ho, W. S. and Jaafar, A. B. Economic and Spatial Planning for Sustainable Oil Palm Biomass Resources to Mitigate Transboundary Haze Issue. *Energy*. 2018. 146: 169-178.

168. Griffin, W. M., Michalek, J., Matthews, H. S. and Hassan, M. N. A. Availability of Biomass Residues for Co-firing in Peninsular Malaysia: Implications for Cost and GHG Emissions in the Electricity Sector. *Energies*. 2014. 7(2): 804-823.

169. Hoo, P. Y., Patrizio, P., Leduc, S., Hashim, H., Kraxner, F., Tan, S. T. and Ho, W. S. Optimal Biomethane Injection into Natural Gas Grid–Biogas from Palm Oil Mill Effluent (POME) in Malaysia. *Energy Procedia*. 2017. 105: 562-569.

170. Hoo, P. Y., Hashim, H., Ho, W. S. and Yunus, N. A. Spatial-Economic Optimisation of Biomethane Injection into Natural Gas Grid: The Case at Southern Malaysia. *Journal of Environmental Management*. 2019. 241: 603-611.

171. Alfonso-Lizarazo, E. H., Montoya-Torres, J. R. and Gutierrez-Franco, E. Modeling Reverse Logistics Process in the Agro-Industrial Sector: The Case of the Palm Oil Supply Chain. *Applied Mathematical Modelling*. 2013. 37(23): 9652-9664.

172. Hadiguna, R. A. and Tjahjono, B. A Framework for Managing Sustainable Palm Oil Supply Chain Operations: A Case of Indonesia. *Production Planning & Control*. 2017. 28(13): 1093-1106.

173. Garcia-Nunez, J. A., Rodriguez, D. T., Fontanilla, C. A., Ramirez, N. E., Lora, E. E. S., Frear, C. S., Stockle, C., Amonette, J. and Garcia-Perez, M. Evaluation of Alternatives for the Evolution of Palm Oil Mills into Biorefineries. *Biomass and Bioenergy*. 2016. 95: 310-329.

174. Rincón, L. E., Valencia, M. J., Hernández, V., Matallana, L. G. and Cardona, C. A. Optimization of the Colombian Biodiesel Supply Chain from Oil Palm Crop Based on Techno-Economical and Environmental Criteria. Energy Economics. 2015. 47: 154-167.

175. Costa, Y., Duarte, A. and Sarache, W. A Decisional Simulation-Optimization Framework for Sustainable Facility Location of a Biodiesel Plant in Colombia. *Journal of Cleaner Production*. 2017. 167: 174-191.

176. IRENA. *Renewable Power Generation Costs in 2019*. Abu Dhabi, United Arab Emirates: International Renewable Energy Agency. 2019.

177. USDA. Oilseeds: World Markets and Trade [Internet]. New York, NY, USA: *USDA Economics, Statistics and Market Information System*; 2020 [updated 2020; cited 2020 September 24]. Available from: https://usda.library.cornell.edu/.

178. Sun, Z., Scherer, L., Tukker, A. and Behrens, P. Linking Global Crop and Livestock Consumption to Local Production Hotspots. *Global Food Security*. 2020. 25: 100323.

179. Prina, M. G., Manzolini, G., Moser, D., Nastasi, B. and Sparber, W. Classification and Challenges of Bottom-Up Energy System Models-A Review. *Renewable and Sustainable Energy Reviews*. 2020. 129: 109917.

180. Börjesson, M., Athanassiadis, D., Lundmark, R. and Ahlgren, E. O. Bioenergy Futures in Sweden–System Effects of CO_2 Reduction and Fossil Fuel Phase-Out Policies. *GCB Bioenergy*. 2015. 7(5): 1118-1135.

181. Daggash, H. A. and Mac Dowell, N. Higher Carbon Prices on Emissions Alone Will Not Deliver the Paris Agreement. *Joule*. 2019. 3(9): 2120-2133.

182. Younis, A., Benders, R., Delgado, R., Lap, T., Gonzalez-Salazar, M., Cadena, A. and Faaij, A. System Analysis of the Bio-Based Economy in Colombia: A Bottom-Up Energy System Model and Scenario Analysis. *Biofuels, Bioproducts and Biorefining*. 2021. 15(2): 481-501.

183. Hagberg, M. B., Pettersson, K. and Ahlgren, E. O. Bioenergy Futures in Sweden–Modeling Integration Scenarios for Biofuel Production. *Energy*. 2016. 109: 1026-1039.

184. Venturini, G., Pizarro-Alonso, A. and Münster, M. How to Maximise the Value of Residual Biomass Resources: The Case of Straw in Denmark. *Applied Energy*. 2019. 250: 369-388.

185. Bramstoft, R., Pizarro-Alonso, A., Jensen, I. G., Ravn, H. and Münster, M. Modelling of Renewable Gas and Renewable Liquid Fuels in Future Integrated Energy Systems. *Applied Energy*. 2020. 268: 114869.

186. Daggash, H. A., Heuberger, C. F. and Mac Dowell, N. The Role and Value of Negative Emissions Technologies in Decarbonising the UK Energy System. *International Journal of Greenhouse Gas Control*. 2019. 81: 181-198.

187. Bogdanov, D., Toktarova, A. and Breyer, C. Transition towards 100% Renewable Power and Heat Supply for Energy Intensive Economies and Severe Continental Climate Conditions: Case for Kazakhstan. *Applied Energy*. 2019. 253: 113606.

188. Hugues, P., Assoumou, E. and Maizi, N. Assessing GHG Mitigation and Associated Cost of French Biofuel Sector: Insights from a TIMES Model. *Energy*. 2016. 113: 288-300.

189. Mathiesen, B. V., Lund, H. and Connolly, D. Limiting Biomass Consumption for Heating in 100% Renewable Energy Systems. *Energy*. 2012. 48(1): 160-168.

190. Kwon, P. S. and Østergaard, P. A. Priority Order in Using Biomass Resources–Energy Systems Analyses of Future Scenarios for Denmark. *Energy*. 2013. 63: 86-94.

191. Hansen, K., Mathiesen, B. V. and Skov, I. R. Full Energy System Transition towards 100% Renewable Energy in Germany in 2050. *Renewable and Sustainable Energy Reviews*. 2019. 102: 1-13.

192. Daggash, H. A. and Mac Dowell, N. Structural Evolution of the UK Electricity System in a Below 2° C World. *Joule*. 2019. 3(5): 1239-1251.

193. Daggash, H. A. and Mac Dowell, N. The Implications of Delivering the UK's Paris Agreement Commitments on the Power Sector. *International Journal of Greenhouse Gas Control*. 2019. 85: 174-181.

194. Caldera, U. and Breyer, C. The Role that Battery and Water Storage Play in Saudi Arabia's Transition to an Integrated 100% Renewable Energy Power System. *Journal of Energy Storage*. 2018. 17, 299-310.

195. Kilickaplan, A., Bogdanov, D., Peker, O., Caldera, U., Aghahosseini, A. and Breyer, C. An Energy Transition Pathway for Turkey to Achieve 100% Renewable Energy Powered Electricity, Desalination and Non-Energetic Industrial Gas Demand Sectors by 2050. *Solar Energy*. 2017. 158: 218-235.

196. König, A. Cost Efficient Utilisation of Biomass in the German Energy System in the Context of Energy and Environmental Policies. *Energy Policy*. 2011. 39(2): 628-636.

197. Lin, T., Rodríguez, L. F., Shastri, Y. N., Hansen, A. C. and Ting, K. C. Integrated Strategic and Tactical Biomass–Biofuel Supply Chain Optimization. *Bioresource Technology*. 2014. 156: 256-266.

198. Akhtari, S., Sowlati, T. and Griess, V. C. Integrated Strategic and Tactical Optimization of Forest-Based Biomass Supply Chains to Consider Medium-Term Supply and Demand Variations. *Applied Energy*. 2018. 213: 626-638.

199. Rentizelas, A. A., Tolis, A. J. and Tatsiopoulos, I. P. Logistics Issues of Biomass: The Storage Problem and the Multi-Biomass Supply Chain. *Renewable and Sustainable Energy Reviews*. 2009. 13(4): 887-894.

200. Wicke, B., van der Hilst, F., Daioglou, V., Banse, M., Beringer, T., Gerssen-Gondelach, S., Heijnen, S., Karssenberg, D., Laborde, D., Lippe, M. and van Meijl, H. Model Collaboration for the Improved Assessment of Biomass Supply, Demand, and Impacts. *GCB Bioenergy*. 2015. 7(3): 422-437.

201. Mahjoub, N., Sahebi, H., Mazdeh, M. and Teymouri, A. Optimal Design of the Second and Third Generation Biofuel Supply Network by a Multi-Objective Model. *Journal of Cleaner Production*. 2020. 256: 120355.

202. Doliente, S. S. and Samsatli, S. Integrated Production of Food, Energy, Fuels and Chemicals from Rice Crops: Multi-Objective Optimisation for Efficient and Sustainable Value Chains. *Journal of Cleaner Production*. 2021. 285: 124900.

203. Andersen, F., Iturmendi, F., Espinosa, S. and Diaz, M. S. Optimal Design and Planning of Biodiesel Supply Chain with Land Competition. *Computers & Chemical Engineering*. 2012. 47: 170-182.

204. Calderón, A. J., Agnolucci, P. and Papageorgiou, L. G. An Optimisation Framework for the Strategic Design of Synthetic Natural Gas (BioSNG) Supply Chains. *Applied Energy*. 2017. 187: 929-955.

205. Khatiwada, D., Leduc, S., Silveira, S. and McCallum, I. Optimizing Ethanol and Bioelectricity Production in Sugarcane Biorefineries in Brazil. *Renewable Energy*. 2016. 85: 371-386.

206. Robles, I., O’Dwyer, E. and Guo, M. Waste-to-Resource Value Chain Optimisation: Combining Spatial, Chemical and Technoeconomic Aspects. *Water Research*. 2020. 178: 115842.

207. Mohseni, S., Pishvaee, M. S. and Sahebi, H. Robust Design and Planning of Microalgae Biomass-to-Biodiesel Supply Chain: A Case Study in Iran. *Energy*. 2016. 111: 736-755.

208. Razm, S., Nickel, S. and Sahebi, H. A Multi-Objective Mathematical Model to Redesign of Global Sustainable Bioenergy Supply Network. *Computers & Chemical Engineering*. 2019. 128: 1-20.

209. Ouraich, I., Wetterlund, E., Forsell, N. and Lundmark, R. A Spatial-Explicit Price Impact Analysis of Increased Biofuel Production on Forest Feedstock Markets: A Scenario Analysis for Sweden. *Biomass and Bioenergy*. 2018. 119: 364-380.

210. Wang, N., Verzijlbergh, R. A., Heijnen, P. W. and Herder, P. M. A Spatially Explicit Planning Approach for Power Systems with a High Share of Renewable Energy Sources. *Applied Energy*. 2020. 260: 114233.

211. Schmidt, J., Leduc, S., Dotzauer, E., Kindermann, G. and Schmid, E. Cost-Effective CO2 Emission Reduction through Heat, Power and Biofuel Production from Woody Biomass: A Spatially Explicit Comparison of Conversion Technologies. *Applied Energy*. 2010. 87(7): 2128-2141.

212. Schmidt, J., Leduc, S., Dotzauer, E. and Schmid, E. Cost-Effective Policy Instruments for Greenhouse Gas Emission Reduction and Fossil Fuel Substitution through Bioenergy Production in Austria. *Energy Policy*. 2011. 39(6): 3261-3280.

213. Guo, M., Richter, G. M., Holland, R. A., Eigenbrod, F., Taylor, G. and Shah, N. Implementing Land-Use and Ecosystem Service Effects into an Integrated Bioenergy Value Chain Optimisation Framework. *Computers & Chemical Engineering*. 2016. 91: 392-406.

214. Ghaderi, H., Moini, A. and Pishvaee, M. S. A Multi-Objective Robust Possibilistic Programming Approach to sustainable switchgrass-based Bioethanol Supply Chain Network Design. *Journal of Cleaner Production*. 2018. 179: 368-406.

215. Abdali, H., Sahebi, H. and Pishvaee, M. The Water-Energy-Food-Land Nexus at the Sugarcane-To-Bioenergy Supply Chain: A Sustainable Network Design Model. *Computers & Chemical Engineering*. 2021. 145: 107199.

216. World Bank. Population, Total – Malaysia [Internet]. Washington, DC: World Bank; 2020 [updated 2020; cited 2020 August 24]. Available from: data.worldbank.org.

217. World Bank. World Bank Country and Lending Groups [Internet]. Washington, DC: World Bank; 2021 [updated 2021; cited 2021 June 08]. Available from: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

218. World Bank. GDP (current US$) [Internet]. Washington, DC: *World Bank*; 2020 [updated 2020; cited 2021 June 08]. Available from: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD.

219. World Bank. *Agricultural Transformation and Inclusive Growth - The Malaysian Experience*. Kuala Lumpur, Malaysia: The World Bank Group (WBG) Global Knowledge and Research Hub. 2019.

220. DOSM. GDP from Agriculture in Malaysia [Internet]. Putrajaya, Malaysia: *Department of Statistics Malaysia*; 2020 [updated 2020; cited 2020 August 17]. Available from: www.dosm.gov.my.

221. DOSM. Selected Agriculture Indicators in Malaysia [Internet]. Putrajaya, Malaysia: *Department of Statistics Malaysia*; 2020 [updated 2020; cited 2020 December 02]. Available from: www.dosm.gov.my.

222. FAO. FAOSTAT [Internet]. Rome, Italy: *Food and Agriculture Organization*; 2021 [updated 2021; cited 2021 June 07]. Available from: http://www.fao.org/faostat/en/#data.

223. MPOC. Monthly Palm Oil Trade Statistics 2017 [Internet]. Selangor, Malaysia: *Malaysian Palm Oil Council*; 2018 [updated 2018; cited 2020 August 05]. Available from: http://mpoc.org.my/monthly-palm-oil-trade-statistics-2017/.

224. KRI. *The Status of the Paddy and Rice Industry in Malaysia*. Kuala Lumpur, Malaysia: Khazanah Research Institute. 2019.

225. BNM. *Food Imports and the Exchange Rate: More Than Meets the Eye, Quarterly Bulletin 2019*. Kuala Lumpur, Malaysia: Bank Negara Malaysia. 2019.

226. FAO. *Livestock's Long Shadow: Environmental Issues and Options*. Rome, Italy: Food and Agriculture Organization. 2006.

227. FAO. *The Future of Food and Agriculture – Alternative Pathways to 2050.* Rome, Italy: Food and Agriculture Organization. 2018.

228. USDA. Oilseeds: World Market and Trade [Internet]. Washington, DC: *USDA Foreign Agricultural Service*; 2018 [updated 2018; cited 2018 November 15]. Available from: https://apps.fas.usda.gov/psdonline/circulars/oilseeds.pdf.

229. Kurnia, J. C., Jangam, S. V., Akhtar, S., Sasmito, A. P. and Mujumdar, A. S. Advances in Biofuel Production from Oil Palm and Palm Oil Processing Wastes: A Review. *Biofuel Research Journal*. 2016. 3(1): 332-346.

230. Ashton-Butt, A., Willcock, S., Purnomo, D., Aryawan, A. A., Wahyuningsih, R., Naim, M., Poppy, G. M., Caliman, J. P., Peh, K. S. H. and Snaddon, J. L. Replanting of First-Cycle Oil Palm Results in a Second Wave of Biodiversity Loss. *Ecology and Evolution*. 2019. 9(11): 6433-6443.

231. Palmoilworld. Oil Palm in Malaysia [Internet]. Washington, DC: *Palmoilworld*; 2011 [updated 2011; cited 2020 August 29]. Available from: http://www.palmoilworld.org/about_malaysian-industry.html.

232. Greenpalm. Palm and Palm Kernel Supply Chain - Fractions Derivatives & Product Uses [Internet]. United Kingdom: *Greenpalm*; 2016 [updated 2016; cited 2020 August 30]. Available from: https://www.greenpalm.org/resources/downloads.

233. Nadzim, U. K. H. M, Yunus, R., Omar, R. and Lim, B. Y. Factors Contributing to Oil Losses in Crude Palm Oil Production Process in Malaysia: A Review. *International Journal of Biomass & Renewables*. 2020. 9(1): 10-24.

234. OECD-FAO. *OECD-FAO Agricultural Outlook 2020-2029*. Paris, France: OECD Publishing. 2020.

235. DOA. *Crop Statistics (Food Crop Sub-Sector)*. Kuala Lumpur, Malaysia: Department of Agriculture Malaysia. 2019.

236. FAO, 2020, GIEWS: Country Brief – Malaysia [Internet]. Rome, Italy: *Food and Agriculture Organization*; 2020 [updated 2020; cited 2021 January 29]. Available from: http://www.fao.org/giews/countrybrief/country.jsp?code=MYS.

237. DOA. *Paddy Production Survey Report – Main Season 2014/2015*. Kuala Lumpur, Malaysia: Department of Agriculture Malaysia. 2016.

238. DOA. *Paddy Production Survey Report – Off Season 2014*. Kuala Lumpur, Malaysia: Department of Agriculture Malaysia. 2015.

239. Lim, J. S., Manan, Z. A., Hashim, H. and Alwi, S. R. W. Synthesis of a Sustainable Integrated Rice Mill Complex. *Journal of Cleaner Production*. 2014. 71: 118-127.

240. Jasmine Food Corporation. Local White Rice [Internet]. Selangor, Malaysia: *Jasmine Food Corporation*; 2016 [updated 2016; cited 2020 August 31]. Available from: http://www.jasmine.com.my/?page_id=138.

241. IRRI. Rice Knowledge Bank – Rice Bran. Philippines: *International Rice Research Institute*; 2018 [updated 2018; cited 2020 August 31]. http://www.knowledgebank.irri.org/step-by-step-production/postharvest/rice-by-products/rice-bran.

242. Wu, J., Elliston, A., Le Gall, G., Colquhoun, I. J., Collins, S. R., Wood, I. P., Dicks, J., Roberts, I. N. and Waldron, K. W. Optimising Conditions for Bioethanol Production from Rice Husk and Rice Straw: Effects of Pre-Treatment on Liquor Composition and Fermentation Inhibitors. *Biotechnology for Biofuels*. 2018. 11(1): 1-13.

243. DOSM. Supply and Utilization Accounts Selected Agricultural Commodities, Malaysia 2013-2019 [Internet]. Putrajaya, Malaysia: Department of Statistics Malaysia; 2020 [updated 2020; cited 2021 June 09]. Available from: https://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=164&bul_id=OTM1TDMzS1IvYm5mU1JiU1Fwekt3UT09&menu_id=Z0VTZGU1UHBUT1VJMFlpaXRRR0xpdz09.

244. Afazeli, H., Jafari, A., Rafiee, S. and Nosrati, M. An Investigation of Biogas Production Potential from Livestock and Slaughterhouse Wastes. *Renewable and Sustainable Energy Reviews*. 2014. 34: 380-386.

245. Zareei, S. Evaluation of Biogas Potential from Livestock Manures and Rural Wastes using GIS in Iran. *Renewable Energy*. 2018. 118: 351-356.

246. Tauseef, S. M., Premalatha, M., Abbasi, T. and Abbasi, S. A. Methane Capture from Livestock Manure. *Journal of Environmental Management*. 2013. 117: 187-207.

247. EIA. Country Analysis Executive Summary: Malaysia [Internet]. Washington, DC: United States Energy Information Administration; 2021 [updated 2021; cited 2021 June 09]. Available from. https://www.eia.gov/international/content/analysis/countries_long/Malaysia/malaysia.pdf.

248. MEIH. Statistics [Internet]. Putrajaya, Malaysia: *Suruhanjaya Tenaga*; 2021 [updated 2021; cited 2021 June 12]. Available from: https://meih.st.gov.my/statistics.

249. ST. *Malaysia Energy Statistics Handbook 2019*. Putrajaya, Malaysia: Suruhanjaya Tenaga. 2020.

250. Liu, Z., Guan, D., Wei, W., Davis, S. J., Ciais, P., Bai, J., Peng, S., Zhang, Q., Hubacek, K., Marland, G. and Andres, R. J. Reduced Carbon Emission Estimates from Fossil Fuel Combustion and Cement Production in China. Nature. 2015. 524(7565): 335-338.

251. IEA. CO_2 emissions [Internet]. Paris, France: *International Energy Agency*; 2021 [updated 2021; cited 2021 June 15]. Available from: https://www.iea.org/data-and-statistics/data-browser?country=MALAYSIA&fuel=CO2%20emissions&indicator=CO2PerCap.

252. Bujang, A. S., Bern, C. J. and Trumm, T. J. Summary of energy demand and Renewable Energy Policies in Malaysia. *Renewable and Sustainable Energy Reviews*. 2016. 53: 1459-1467.

253. Tang, C.F. and Tan, E. C. Exploring the Nexus of Electricity Consumption, Economic Growth, Energy Prices and Technology Innovation in Malaysia. *Applied Energy*. 2013. 104: 297-305.

254. Ali, R., Daut, I. and Taib, S. A Review on Existing and Future Energy Sources for Electrical Power Generation in Malaysia. *Renewable and Sustainable Energy Reviews*. 2012. 16(6): 4047-4055.

255. Shamsuddin, A. H. Development of Renewable Energy in Malaysia-Strategic Initiatives for Carbon Reduction in the Power Generation Sector. *Procedia Engineering*. 2012. 49: 384-391.

256. DOE. *Environmental Quality (Clean Air) Regulations 2014*. Putrajaya, Malaysia: Department of Environment Malaysia. 2014.

257. IEA. Nationally Determined Contribution (NDC) to the Paris Agreement: Malaysia [Internet]. Paris, France: *International Energy Agency*; 2020: [updated 2020; cited 2020 October 05]. Available from: https://www.iea.org/policies/11766-nationally-determined-contribution-ndc-to-the-paris-agreement-malaysia?country=Malaysia&qs=malaysia.

258. NRE. *Biennial Update report to the UNFCCC*. Putrajaya, Malaysia: Ministry of Natural Resources and Environment Malaysia. 2015.

259. MESTECC. *Third National Communication and Second Biennial Update Report to the UNFCCC*. Putrajaya, Malaysia: Ministry of Energy, Science, Technology, Environment and Climate Change Malaysia. 2018.

260. KeTTHA. *National Renewable Energy Policy and Action Plan*. Putrajaya, Malaysia: Ministry of Energy, Green Technology and Water Malaysia. 2009.

261. PNMB. *Laws of Malaysia (Act 725): Renewable Energy Act 2011*. Kuala Lumpur, Malaysia: Malaysia's National Printer. 2011.

262. KeTTHA. *Green Technology Master Plan 2017-2030*. Putrajaya, Malaysia: Ministry of Energy, Green Technology and Water. 2017.

263. SEDA. *National Renewable Energy Policy*. Putrajaya, Malaysia: Sustainable Energy Development Authority Malaysia; 2019 [updated 2019; cited 2020 October 05]. Available from: https://www.seda.gov.my/policies/national-renewable-energy-policy-and-action-plan-2009/.

264. ST. *Report on Peninsular Malaysia Generation Development Plan 2019 (2020 – 2030)*. Putrajaya, Malaysia: Suruhanjaya Tenaga. 2020.

265. MPIC. *National Biofuel Policy 2006*. Putrajaya, Malaysia: Ministry of Plantation Industries and Commodities. 2006.

266. EPU. *The Eleventh Malaysia Plan 2016–2020*. Putrajaya, Malaysia: Economic Planning Unit Malaysia. 2016.

267. Shah, S. A. B20 Biodiesel Available throughout Malaysia by Next June. *The Malaysian Reserve* [Internet]. 2020 September 10. [cited 2019 October 07]. Available from: https://themalaysianreserve.com/2020/09/10/b20-biodiesel-available-throughout-malaysia-by-next-june/.

268. OECD-FAO. *OECD-FAO Agricultural Outlook 2018-2027*. Paris, France: OECD Publishing. 2018.

269. SIRIM. MYREMap. *SIRIM Environmental Technology Research Centre* [Internet]. 2014. Available from: https://gisportal.sirim.my/.

270. Petersen, R., Aksenov, D., Esipova, E., Goldman, E., Harris, N., Kuksina, N., Kurakina, I., Loboda, T., Manisha, A., Sargent, S. and Shevade, V. *Mapping tree plantations with multispectral imagery: Preliminary results for seven tropical countries*. Washington, DC: World Resources Institute and Transparent World. 2015.

271. Nelson, A. and Gumma, M. K. *A Map of Lowland Rice Extent in the Major Rice Growing Countries of Asia*. Philippines: International Rice Research Institute. 2015.

272. Gravalos, I., Xyradakis, P., Kateris, D., Gialamas, T., Bartzialis, D. and Giannoulis, K. An Experimental Determination of Gross Calorific Value of Different Agroforestry Species and Bio-Based Industry Residues. *Natural Resources*. 2016. 7: 57-68.

273. Biswas, B., Pandey, N., Bisht, Y., Singh, R., Kumar, J. and Bhaskar, T. Pyrolysis of Agricultural Biomass Residues: Comparative Study of Corn Cob, Wheat Straw, Rice Straw and Rice Husk. *Bioresource Technology*. 2017. 237: 57-63.

274. World Bank. Commodity Markets. Washington, DC: World Bank; 2018 [updated 2018; cited 2019 February 28]. Available from: https://www.worldbank.org/.

275. Harahap. F., Silveira. S., Khatiwada. D. Cost Competitiveness of Palm Oil Biodiesel Production in Indonesia. *Energy*. 2019. 170: 62-72.

276. Gilbert, M., Nicolas, G., Cinardi, G., Van Boeckel, T. P., Vanwambeke, S. O., Wint, G. W. and Robinson, T. P. Global Distribution Data for Cattle, Buffaloes, Horses, Sheep, Goats, Pigs, Chickens and Ducks in 2010. *Scientific Data*. 2018. 5(1): 1-11.

277. Sung, C. T. B. *Availability, Use, and Removal of Oil Palm Biomass in Indonesia*. United States: The International Council on Clean Transportation. 2016.

278. ST. *Peninsular Malaysia Electricity Supply Outlook 2017*. Putrajaya, Malaysia: Suruhanjaya Tenaga. 2017.

279. ST. *Piped Gas Distribution Industry Statistics 2016*. Putrajaya, Malaysia: Suruhanjaya Tenaga. 2018.

280. ST. *Performance and Statistical Information on Electricity Supply Industry in Malaysia*. Putrajaya, Malaysia: Suruhanjaya Tenaga. 2019.

281. Schiavina, M., Freire, S. and MacManus, Kytt. GHS population grid multitemporal (1975, 1990, 2000, 2015) R2019A. *European Commission Joint Research Centre (JRC)* [Internet]. 2019. Available from: http://data.europa.eu/89h/0c6b9751-a71f-4062-830b-43c9f432370f.

282. Reddy, B. R. and Vinu, R. Microwave Assisted Pyrolysis of Indian and Indonesian Coals and Product Characterization. *Fuel Processing Technology*. 2016. 154: 96-103.

283. EPA. *Emission Factors for Greenhouse Gas Inventories*. DC, United States: United States Environmental Protection Agency. 2018.

284. EIA. *Capital Cost Estimates for Utility Scale Electricity Generating Plants*. Washington, DC: United States Energy Information Administration. 2016.

285. ST. *Electricity Tariff Review in Peninsular Malaysia for Regulatory Period 2 (RP2: 2018-2020) under Incentive-Based Regulation (IBR) Mechanism*. Putrajaya Malaysia: Suruhanjaya Tenaga. 2018.

286. IEA-ETSAP. *Technology Brief E16 – District Heating*. Paris, France: IEA-ETSAP Energy Technology Systems Analysis. 2013.

287. Trading Economics. *Malaysia Gasoline Prices*. New York, NY: Trading Economics; 2021 [updated 2021: 2021 May 05]. Available from: https://tradingeconomics.com/malaysia/gasoline-prices.

288. IEA. *World Energy Outlook 2018*. Paris, France: OECD Publishing. 2018.

289. ESA-CCI. ESA Climate Change Initiative - Land Cover led by UCLouvain. *ESA Climate Change Initiative* [Internet]. 2017. Available from: http://maps.elie.ucl.ac.be/CCI/viewer/download.php.

290. IUCN, UNEP-WCMC. The World Database on Protected Areas (WDPA) [On-line] [05/2017] [Internet]. Cambridge, UK: *Protected Planet*; 2017 [updated 2017: cited 2017 May 05]. Available from: www.protectedplanet.net.

291. OpenStreetMap. Open Database License. *OpenStreetMap* [Internet]. 2019. Available from: https://www.openstreetmap.org.

292. Jarvis, A., Reuter, H. I., Nelson, A. and Guevara, E. Hole-filled seamless SRTM Data V4. *International Centre for Tropical Agriculture (CIAT)* [Internet]. 2008. Available from: https://srtm.csi.cgiar.org.

293. Cheng, V. K. and Hammond, G. P. Life-Cycle Energy Densities and Land-Take Requirements of Various Power Generators: A UK Perspective. *Journal of Energy Institute*. 2017. 90: 201-213.

294. Hoo, P. Y., Hashim, H. and Ho, W. S. Opportunities and Challenges: Landfill Gas to Biomethane Injection into Natural Gas Distribution Grid through Pipeline. *Journal of Cleaner Production*. 2018. 175: 409-19.

295. Agar, D. A. A comparative economic analysis of torrefied pellet production based on state-of-the-art pellets. *Biomass and Bioenergy*. 2017. 97: 155-161.

296. Batidzirai, B., Mignot, A. P. R., Schakel, W. B., Junginger, H. M. and Faaij, A. P. C. Biomass Torrefaction Technology: Techno-Economic Status and Future Prospects. *Energy*. 2013. 62: 196-214.

297. Talero, G., Rincón, S. and Gómez, A. Biomass Torrefaction in a Standard Retort: A study on oil palm solid residues. *Fuel*. 2019. 244: 366-378.

298. MPOB-NKEA. *National Biogas Implementation (EPP5) - Biogas Capture and CDM Project Implementation for Palm Oil Mills*. Selangor, Malaysia: National Key Economic Areas. 2013.

299. Rotunno, P., Lanzini, A. and Leone, P. Energy and Economic Analysis of a Water Scrubbing Based Biogas Upgrading Process for Biomethane Injection into the Gas Grid or Use as Transportation Fuel. *Renewable Energy*. 2017. 102: 417-32.

300. IRENA. *Renewable Power Generation Costs in 2017*. Abu Dhabi, UAE: International Renewable Energy Agency. 2018

301. Cigala, C. *Sustainable Energy Handbook. Module 6.1: Simplified Financial Models*. Colorado, United States: MWH Global. 2016.

302. S2biom. Tools for Biomass Chains. *S2biom* [Internet]. 2017. Available from: http://S2biom-test.alterra.wur.nl/web/guest/bio2match.

303. Dimitriou, I., Goldingay, H. and Bridgwater, A. V. Techno-Economic and Uncertainty Analysis of Biomass to Liquid (BTL) Systems for Transport Fuel Production. *Renewable and Sustainable Energy Reviews*. 2018. 88: 160-75.

304. Abdullah, S. S. B. S. *Efficient Bioethanol Production from Oil Palm Frond Petiole*. Ph.D. Thesis. Kyushu Institute of Technology; 2015.

305. Ebadian, M., Sowlati, T., Sokhansanj, S., Townley-Smith, L. and Stumborg, M. Modeling and Analysing Storage Systems in Agricultural Biomass Supply Chain for Cellulosic Ethanol Production. *Applied Energy*. 2013. 102: 840-849.

306. CPLEX. Software. United States: *International Business Machines Corporation*. 2009.

307. Carbon Brief. Carbon Brief's Paris Climate Pledge Tracker: INDC Database [Internet]. London, United Kingdom: *Carbon Brief*; 2015. [updated 2015; cited 2020 October 05]. Available from: https://www.carbonbrief.org/paris-2015-tracking-country-climate-pledges.

308. IRENA. *Global Renewables Outlook: Energy Transformation 2050*. Abu Dhabi, United Arab Emirates: International Renewable Energy Agency. 2019.

309. Ayompe, L. M., Schaafsma, M. and Egoh, B. N. Towards Sustainable Palm Oil Production: The Positive and Negative Impacts on Ecosystem Services and Human Wellbeing. *Journal of Cleaner Production*. 2020. 278: 123914.

310. How, B. S., Ngan, S. L., Hong, B. H., Lam, H. L., Ng, W. P. Q., Yusup, S., Ghani, W. A. W. A. K., Kansha, Y., Chan, Y. H., Cheah, K. W. and Shahbaz, M. An Outlook of Malaysian Biomass Industry Commercialisation: Perspectives and Challenges. *Renewable and Sustainable Energy Reviews*. 2019. 113: 109277.

311. Boundy, R. G., Diegel, S. W., Wright, L. L. and Davis, S. C. *Biomass Energy Data Book*. 4th ed. Tennessee: Oak Ridge National Laboratory (ORNL). 2011.

312. Peters, M. S., Timmerhaus, K. and West, R. *Plant Design and Economics for Chemical Engineers*. 5th ed. New York: McGraw-Hill. 2002.

313. Dahunsi, S. O., Fagbiele, O. O. and Yusuf, E. O. Bioenergy Technologies Adoption in Africa: A Review of Past and Current Status. *Journal of Cleaner Production*. 2020. 264: 121683.

314. Lucena, A. F., Clarke, L., Schaeffer, R., Szklo, A., Rochedo, P. R., Nogueira, L. P., Daenzer, K., Gurgel, A., Kitous, A. and Kober, T. Climate Policy Scenarios in Brazil: A Multi-Model Comparison for Energy. *Energy Economics*. 2016. 56: 564-574.

315. Hansen, U. E. and Ockwell, D. Learning and technological Capability Building in Emerging Economies: The Case of the Biomass Power Equipment Industry in Malaysia. *Technovation*. 2014. 34(10): 617-630.

316. Wang, T., Huang, H., Yu, C., Fang, K., Zheng, M. and Luo, Z. Understanding Cost Reduction of China's Biomass Direct Combustion Power Generation—A Study Based on Learning Curve Model. *Journal of Cleaner Production*. 2018. 188: 546-555.

317. Jablonski, S., Strachan, N., Brand, C. and Bauen, A. The Role of Bioenergy in the UK’s Energy Future Formulation and Modelling of Long-Term UK Bioenergy Scenarios. *Energy Policy*. 2010. 38(10): 5799-5816.

318. Forsell, N., Guerassimoff, G., Athanassiadis, D., Thivolle-Casat, A., Lorne, D., Millet, G. and Assoumou, E. Sub-National TIMES Model for Analyzing Future Regional Use of Biomass and Biofuels in Sweden and France. *Renewable Energy*. 2013. 60: 415-426.

319. Fehrenbach, D., Merkel, E., McKenna, R., Karl, U. and Fichtner, W. On the Economic Potential for Electric Load Management in the German Residential Heating Sector–An Optimising Energy System Model Approach. *Energy*. 2014. 71: 263-276.

320. Börjesson, M., Ahlgren, E. O., Lundmark, R. and Athanassiadis, D. Biofuel Futures in Road Transport–A Modeling Analysis for Sweden. *Transportation Research Part D: Transport and Environment*. 2014. 32: 239-252.

321. Gironès, V. C., Moret, S., Peduzzi, E., Nasato, M. and Maréchal, F. Optimal Use of Biomass in Large-Scale Energy Systems: Insights for Energy Policy. *Energy*. 2017. 137: 789-797.

322. Tsiropoulos, I., Hoefnagels, R., van den Broek, M., Patel, M. K. and Faaij, A. P. The Role of Bioenergy and Biochemicals in CO_2 Mitigation through the Energy System–A Scenario Analysis for The Netherlands. *GCB Bioenergy*. 2017. 9(9): 1489-1509.

323. Tsiropoulos, I., Hoefnagels, R., de Jong, S., van den Broek, M., Patel, M. and Faaij. A. Emerging Bioeconomy Sectors in Energy Systems Modeling–Integrated Systems Analysis of Electricity, Heat, Road Transport, Aviation, and Chemicals: A Case Study for the Netherlands. *Biofuels, Bioproducts and Biorefining*. 2018. 12(4): 665-693.

324. Jordan, M., Lenz, V., Millinger, M., Oehmichen, K. and Thrän, D. Future Competitive Bioenergy Technologies in the German Heat Sector: Findings from an Economic Optimization Approach. *Energy*. 2019. 189: 116194.

325. Jordan, M., Millinger, M. and Thrän, D. Robust Bioenergy Technologies for the German Heat Transition: A Novel Approach Combining Optimization Modeling with Sobol'sensitivity Analysis. *Applied Energy*. 2020. 262: 114534.

326. Millinger, M., Meisel, K. and Thrän, D. Greenhouse Gas Abatement Optimal Deployment of Biofuels from Crops in Germany. *Transportation Research Part D: Transport and Environment*. 2019. 69: 265-275.

327. van Meijl, H., Tsiropoulos, I., Bartelings, H., Hoefnagels, R., Smeets, E., Tabeau, A. and Faaij, A. On the Macro-Economic Impact of Bioenergy and Biochemicals–Introducing Advanced Bioeconomy Sectors into an Economic Modelling Framework with a Case Study for the Netherlands. *Biomass and Bioenergy*. 2018. 108: 381-397.

328. Lap, T., Benders, R., Köberle, A., van der Hilst, F., Nogueira, L., Szklo, A., Schaeffer, R. and Faaij, A. Pathways for a Brazilian Biobased Economy: towards Optimal Utilization of Biomass. *Biofuels, Bioproducts and Biorefining*. 2019. 13(3): 673-689.

329. Akgul, O., Shah, N. and Papageorgiou, L. G. Economic Optimisation of a UK Advanced Biofuel Supply Chain. *Biomass and Bioenergy*. 2012. 41: 57-72.

330. Kostin, A. M., Guillén-Gosálbez, G., Mele, F. D., Bagajewicz, M. J. and Jiménez, L. Design and Planning of Infrastructures for Bioethanol and Sugar Production under Demand Uncertainty. *Chemical Engineering Research and Design*. 2012. 90(3): 359-376.

331. Devlin, G. and Talbot, B. Deriving cooperative Biomass Resource Transport Supply Strategies in Meeting Co-firing Energy Regulations: A Case for Peat and Wood Fibre in Ireland. *Applied Energy*. 2014. 113: 1700-1709.

332. Kraxner, F., Aoki, K., Leduc, S., Kindermann, G., Fuss, S., Yang, J., Yamagata, Y., Tak, K. I. and Obersteiner, M. BECCS in South Korea—Analyzing the Negative Emissions Potential of Bioenergy as a Mitigation Tool. *Renewable Energy*. 2014. 61: 102-108.

333. Natarajan, K., Leduc, S., Pelkonen, P., Tomppo, E. and Dotzauer, E. Optimal Locations for Second Generation Fischer Tropsch Biodiesel Production in Finland. *Renewable Energy*. 2014. 62: 319-330.

334. Ahn, Y. C., Lee, I. B., Lee, K. H. and Han, J. H. Strategic Planning Design of Microalgae Biomass-To-Biodiesel Supply Chain Network: Multi-Period Deterministic Model. *Applied Energy*. 2015. 154: 528-542.

335. Zetterholm, J., Pettersson, K., Leduc, S., Mesfun, S., Lundgren, J. and Wetterlund, E. Resource Efficiency or Economy of Scale: Biorefinery Supply Chain Configurations for Co-Gasification of Black Liquor and Pyrolysis Liquids. *Applied Energy*. 2018. 230: 912-924.

336. Ahlström, J. M., Zetterholm, J., Pettersson, K., Harvey, S. and Wetterlund, E. Economic Potential for Substitution of Fossil Fuels with Liquefied Biomethane in Swedish Iron and Steel Industry–Synergy and Competition with Other Sectors. *Energy Conversion and Management*. 2020. 209: 112641.

337. Nwachukwu, C. M., Wang, C. and Wetterlund, E. Exploring the Role of Forest Biomass in Abating Fossil CO2 Emissions in the Iron and Steel Industry–The Case of Sweden. *Applied Energy*. 2021. 288: 116558.

338. Sharifzadeh, M., Garcia, M. C. and Shah, N. 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 and Bioenergy*. 2015. 81: 401-414.

339. Sosa, A., Acuna, M., McDonnell, K. and Devlin, G. Managing the Moisture Content of Wood Biomass for the Optimisation of Ireland's Transport Supply Strategy to Bioenergy Markets and Competing Industries. *Energy*. 2015. 86: 354-368.

340. Mohseni, S. and Pishvaee, M. S. A Robust Programming Approach towards Design and Optimization of Microalgae-Based Biofuel Supply Chain. *Computers & Industrial Engineering*. 2016. 100: 58-71.

341. Murphy, F., Sosa, A., McDonnell, K., Devlin, G. Life Cycle Assessment of Biomass-to-Energy Systems in Ireland Modelled with Biomass Supply Chain Optimisation Based on Greenhouse Gas Emission Reduction. *Energy*. 2016. 109: 1040-1055.

342. Santibañez-Aguilar, J. E., Morales-Rodriguez, R., González-Campos, J. B. and Ponce-Ortega, J. M. Stochastic Design of Biorefinery Supply Chains Considering Economic and Environmental Objectives. *Journal of Cleaner Production*. 2016. 136: 224-245.

343. Thrän, D., Arendt, O., Banse, M., Braun, J., Fritsche, U., Gärtner, S., Hennenberg, K.J., Hünneke, K., Millinger, M., Ponitka, J. and Rettenmaier, N. Strategy Elements for a Sustainable Bioenergy Policy Based on Scenarios and Systems Modeling: Germany as Example. *Chemical Engineering & Technology*. 2017. 40(2): 211-226.

344. Millinger, M., Ponitka, J., Arendt, O. and Thrän, D. Competitiveness of Advanced and Conventional Biofuels: Results from Least-Cost Modelling of Biofuel Competition in Germany. *Energy Policy*. 2017. 107: 394-402.

345. Millinger, M. and Thrän, D. Biomass Price Developments Inhibit Biofuel Investments and Research in Germany: The Crucial Future Role of High Yields. *Journal of Cleaner Production*. 2018. 172: 1654-1663.

346. Millinger, M., Meisel, K., Budzinski, M. and Thrän, D. Relative Greenhouse Gas Abatement Cost Competitiveness of Biofuels in Germany. Energies. 2018. 11(3): 615.

347. Roni, M. S., Eksioglu, S. D., Cafferty, K. G. and Jacobson, J. J. A Multi-Objective, Hub-and-Spoke Model to Design and Manage Biofuel Supply Chains. *Annals of Operations Research*. 2017. 249(1-2): 351-380.

348. Rabbani, M., Saravi, N. A., Farrokhi-Asl, H., Lim, S. F. W., & Tahaei, Z. (2018). Developing a sustainable supply chain optimization model for switchgrass-based bioenergy production: a case study. Journal of Cleaner Production, 200, 827-843.

349. Robles, I., Durkin, A. and Guo, M. Stochastic Optimisation of Organic Waste-to-Resource Value Chain. *Environmental Pollution*. 2021. 273: 116435.

350. USAID. Handbook POME-to-Biogas Project Development in Indonesia. 2nd ed. Washington, DC: *United States Agency for International Development*. 2015.

351. Lee, S. H., Lee, T. H., Jeong, S. M. and Lee, J. M. Economic Analysis of a 600 MWe Ultra Supercritical Circulating Fluidized Bed Power Plant Based on Coal Tax and Biomass Co-Combustion Plans. *Renewable Energy*. 2019. 138, 121-127.

352. NETL. *Cost and Performance Baseline for Fossil Energy Plants Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity Revision 3*. United States: National Energy Technology Laboratory. 2015.

LIST OF PUBLICATIONS

Journal with Impact Factor

1. **Mohd Idris, M. N**., Leduc, S., Yowargana, P., Hashim, H. and Kraxner, F. Spatio-Temporal Assessment of the Impact of Intensive Palm Oil-Based Bioenergy Deployment on Cross-Sectoral Energy Decarbonization. *Applied Energy*. 2021. 285: 116460. **(Q1, IF: 9.746)**
2. **Mohd Idris, M. N.**, Hashim, H., Leduc, S., Yowargana, P. and Kraxner, F. Deploying Bioenergy for Decarbonizing Malaysian Energy Sectors and Alleviating Renewable Energy Poverty. *Energy*. 2021. 232: 120967. **(Q1, IF: 7.147)**
3. **Mohd Idris, M. N.** and Hashim, H. Integrating Palm Oil Biomass Waste Utilization in Coal-Fired Power Plants for Meeting Near-Term Emission Targets. *Journal of Environmental Management*. 2021. 296: 113118. **(Q1, IF: 6.789)**
4. **Mohd Idris, M. N.**, Hashim, H. and Razak, N. H. Spatial Optimisation of Oil Palm Biomass Co-firing for Emissions Reduction in Coal-Fired Power Plant. *Journal of Cleaner Production*. 2018. 172: 3428-3447. **(Q1, IF: 9.297)**

Indexed Conference Paper

1. **Mohd Idris, M. N.** and Hashim, H. Modeling Near-Term Bioenergy Strategy to Meet the Emission Target: Production of Solid Biofuel to Scale Up Co-Firing. *Chemical Engineering Transactions*. 2020. 81: 1099-1104. **(Indexed by Scopus)**
2. **Nurariffudin, M.**, Hashim, H. and Lee, C.T. Spatial Biomass Resource Planning Framework for Co-firing under Carbon Policy Scheme. *Chemical Engineering Transactions*. 2018. 63: 445-450. **(Indexed by Scopus)**
3. **Nurariffudin, M.**, Hashim, H., Lim, J. S. and Ho, C. S. Economic Assessment of Microalgae-Based CO_2 Utilization in Power Plant Sector in Malaysia. *Chemical Engineering Transactions*. 2017. 56: 643-648. **(Indexed by Scopus)**