Regional development models with clean coal power plants

Mr. Christoph Casimir Odermatt

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By	Mr. Christoph Casimir Odermatt
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Accepted by the Faculty of Economics, Chulalongkorn University in Partial Fulfillment of the Requirements for the Doctoral Degree

....Dean of the Faculty of Economics
(Professor Worawet Suwanrada, Ph.D.)

THESIS COMMITTEE

....Chairman
(Associate Professor Sothitorn Mallikamas, Ph.D.)

....Thesis Advisor
(Associate Professor Pongsa Pornchaiwiseskul, Ph.D.)

....Examiner
(Associate Professor Paitoon Kraipornsak, Ph.D.)

....Examiner
(Assistant Professor San Sampattavanija, Ph.D.)

....External Examiner
(Assistant Professor Papusson Chaiwat, Ph.D.)

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วิทยานิพนธ์เล่มนี้ได้รวมการศึกษา 3 ด้าน อันเกี่ยวข้องกับการผลิตไฟฟ้าจากเทคโนโลยีถ่านหินสะอาดซึ่งถูกนำมาใช้ในโรงงานผลิตไฟฟ้าในประเทศไทย การคาดการณ์ผลกระทบทางเศรษฐกิจในแง่ของโครงสร้างทางเศรษฐกิจทางภาคใต้ของประเทศไทยโดยใช้ตารางปัจจัยการผลิตและผลผลิต การศึกษาต้นทุนสัมพัทธ์โดยเปรียบเทียบรวมถึงปริมาณก๊าซคาร์บอนไดออกไซด์ที่ถูกปล่อยออกมาเนื่องจากการใช้เทคโนโลยีถ่านหินสะอาดเมื่อเปรียบเทียบกับการใช้เทคโนโลยีอื่นเพื่อใช้ในการคำนวณราคาการปล่อยก๊าซคาร์บอนไดออกไซด์ในตลาดคาร์บอน นอกจากนี้ ยังได้ศึกษาถึงการคำนวณค่าไฟฟ้าที่มีราคาสูงซึ่งผู้บริโภคต้องแบกรับอันเนื่องมาจากเงินอุดหนุนด้านพลังงานแสงอาทิตย์ถูกผลักไว้ในค่าไฟฟ้าจากโครงการหลากหลายโครงการที่มีความแตกต่างกัน

ผลการศึกษาพบว่า มีการเปลี่ยนแปลงเพียงเล็กน้อยในโครงสร้างทางเศรษฐกิจทางภาคใต้ของประเทศไทยควบคู่ไปกับการเพิ่มสูงขึ้นของระดับเทคโนโลยีในภาคอุตสาหกรรมการผลิต ธุรกิจบริการ การซ่อมแซม การค้า และการก่อสร้าง ยิ่งไปกว่านั้น การผลิตไฟฟ้าจากถ่านหินสะอาดทางเลือกใหม่นับเป็นทางเลือกการผลิตไฟฟ้าที่มีเสถียรภาพและมีค่าใช้จ่ายที่ค่อนข้างต่ำในด้านของต้นทุนการจัดการมลพิษเมื่อเปรียบเทียบกับเทคโนโลยีการผลิตไฟฟ้าประเภทอื่น ๆ ในขณะที่ก๊าซธรรมชาติไม่ได้เป็นทางเลือกที่ถูกนำมาใช้อย่างแพร่หลายในปัจจุบัน รวมถึงการผลิตไฟฟ้าจากพลังงานแสงอาทิตย์ก็มีต้นทุนการผลิตที่ค่อนข้างสูง ดังนั้น การใช้ถ่านหินสะอาดในฐานะที่เป็นพลังงานทางเลือกหรือพลังงานผสมผสานจึงเป็นวิธีการที่ค่อนข้างสมเหตุสมผล รัฐบาลควรลดการอุดหนุนด้านพลังงานแสงอาทิตย์ต่อหน่วย ซึ่งจะเป็นแนวทางที่ส่งเสริมและผลักดันให้เกิดการขับเคลื่อนการพัฒนาอุตสาหกรรมนี้ในภาคเอกชนต่อไป

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ปีการศึกษา 2560	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

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CHRISTOPH CASIMIR ODERMATT: Regional development models with clean coal power plants. ADVISOR: ASSOC. PROF. PONGSA PORNCHAIWISESKUL, Ph.D., pp.

This thesis examines clean coal technology to be used in Thailand in three studies. The economic impacts on the economic structure of southern Thailand are forecasted with the input-output method. Further, the relative levelized costs of clean coal energy relative to its amount of carbon equivalent emissions are compared to other technologies and their carbon equivalent emissions in order to compute a carbon certificate price. Lastly, the costs of the solar subsidy on the end consumer is calculated in different scenarios.

The results suggest that there may be slight changes in the economic structure in southern Thailand with increases in the higher technology manufacturing sector, in the services sector and in repair, trade and construction. Furthermore, new clean coal is a sensible choice for stable and cheap energy, at the cost of more pollution compared to other current technologies. Natural gas is politically not an option, and solar is still quite expensive. Lastly, the solar power subsidy comes at a cost in all scenarios. The limit on yearly new solar power installations that are covered with the solar subsidy should be replaced with a decrease in the solar power subsidy per energy unit over time. This would increase the total generating capacity by solar power.

Field of Study:	Economics	Student's Signature	....
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ABBREVIATIONS

BAU	Business-as-usual
CC	Combined-cycle
CCS	Carbon dioxide capture and storage
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CSP	Concentrating solar power
EGAT	Electricity Generating Authority of Thailand
EPPO	Energy Policy and Planning Office
ERC	Energy Regulatory Commission
ETS	Emission Trading Scheme
EU	European Union
FiT	Feed-in tariff
GHG	Greenhouse gas
GW	Gigawatt
GWh	Gigawatt-hours
IGCC	Integrated Gasification Combined-Cycle
IO	Input-output
IRENA	International Renewable Energy Agency
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
kWh	Kilowatt-hour
LCA	Lifecycle assessment
LCOE	Levelized costs of energy
MW	Megawatt
MWh	Megawatt-hour
NO_X	Mono-nitrogen oxides
NPV	Net present value

OECD	Organisation for Economic Co-ordination and Development
O&M	Operation and maintenance
PDP2015	Power Development Plan 2015
PV	Photovoltaic
RAS	Richard Stone's A matrix manipulation
SO_2	Sulfur dioxide
SPP	Small power producer
US	United States of America
USD	United States dollar
VSPP	Very small power producer
WACC	Weighted average cost of capital

Section 1

1 Introduction

This thesis is composed of three studies. The studies touch the fields of regional development, energy economics, and environmental economics.

The first study is called ‘Clean coal power plants and their regional economic impact’. The study features calculations and manipulations with the German and Thai input-output (IO) tables. The IO tables are regionalized to forecast the structural changes on the regional economy that will occur after a clean coal power plant is built in southern Thailand. The results show that there are some positive effects on the economy in southern Thailand, in that there is increased demand from the electricity producing sector for inputs from the electricity sector itself, the trade and repair sector, the service sector, electrical machinery sector, and building construction and public works sector. In total, there is a positive effect, decreasing over time, on the gross regional product of around 0.5% per year, after all three proposed clean coal units are built.

The second study estimates levelized costs of energy (LCOE) of different power plant technologies and relates them to their direct emissions. The study is called ‘Clean coal project: carbon certificate pricing’. It is related to the first study in a subtle way in that it also features clean coal technology. The model estimates a theoretical carbon certificate price to render power plant technologies that could replace either the old or the new clean coal power plant economically viable. The results show that the policy maker’s choice to build some units of clean coal is reasonable, considering costs, some lower pollution exhaust versus the old clean coal technology, and a stable electric energy supply. Wind power is cheaper and cleaner but does not have enough energy potential to replace the proposed energy supply that is supposed to be produced by clean coal. Natural gas power would be an option too, if a less polluting technology is preferred, however, there is a political decision to reduce the dependency on natural gas. Lastly, utility-scale solar power has the energy potential in Thailand to replace clean coal, however at a relative prohibitive cost.

The third study is titled ‘Feed-in tariffs for solar energy in Thailand’. This study examines the costs of the solar feed-in tariffs (FiT) in Thailand. The renewable electric energy will mostly be produced by small and very small independent power producers. To calculate the costs of the FiT, the price of the tariff is compared to the LCOE calculated in the second study. The solar FiT will help to increase the share of solar, and renewables altogether, in the electricity mix. However, it will also increase prices for electricity consumers. The results show a comparison of how much cheaper an electric energy unit would be for the consumer if clean coal instead of solar is being used. Further, the results also portray different accumulated solar power generation scenarios by 2036 and compares costs for these scenarios for the end-user. These results reveal that the solar subsidy comes at a cost, but if learning for the FiT is implemented that reduces the FiT with lower solar power costs, then the subsidy cost will not be exorbitant.

The first study’s contributions to the literature is a forecast of the regional IO table of a cluster of provinces in southern Thailand and the method constructing this regional table. The second study’s produces theoretical carbon dioxide ($CO_{2)}$ certificate prices of different power plant technologies in order for them to be able to replace the old or new clean coal or gas power plants in Thailand on an economically viable basis. The third study delivers estimations of future electricity tariff price increases, if the policy maker would relax the yearly new solar power installations limit, respectively abolish the FiT and only build clean coal power.

Thesis section 2 embodies the research proposal with each studies’ research questions, objectives and hypothesis. The motivation and justification on the thesis’ topic that uses clean coal technology in Thailand is laid down in section 3. Sections 4-6 feature each study separately. The studies are in turn composed of their own introduction, literature review, model, results, and conclusions. In section 7 at the end of the thesis, overall conclusions are drawn. The section is compromised of the main findings, policy suggestions, contributions to the literature, limitations of the thesis and ideas for further studies.

Section 2

2 Research proposal

2.1 Clean coal power plants and their regional economic impact

This study calculates the impacts of the Electricity Generating Authority of Thailand's (EGAT) forthcoming construction of clean coal power plants in southern Thailand on that regional economy. This provides answers on how the economy in that region will transform from the additional investment. The results may be applied for similar projects in Thailand and other countries with similar characteristics for cost-benefit analyses. The IO model method is applied to assess the impact. IO tables provide a micro level tool to measure or forecast public investment programs. Hence, with the IO table, various regional development studies can be undertaken, and the results may then be used for policy recommendations. The forecast that this study produces should be compared with the real outcome after the construction in order to assess the forecast and its methods; and to amend the forecasting method to construct a more precise forecast, if necessary. In addition, a specific method will be defined on how to transform the national IO table to the assigned regions in Germany and Thailand. This method could be used to construct other regional IO tables in Thailand.

The actual research question asks, how will the economy in Southern Thailand transform after EGAT will have replaced the existing capacity with supercritical high-efficiency low-emission coal energy technology and which sectors will benefit most in input demand growth?

The objectives are to first forecast a Thai 2015 IO table with Richard Stone's A matrix manipulation (RAS) method. Then, to identify a method to regionalize the Thai and German national IO tables, to then create a regional IO table for Brandenburg and southern Thailand with that method. Furthermore, after the power plants has been built, a forecast of the economic structure of this cluster of provinces needs to be made. And finally, the regional IO table for southern Thailand is analyzed.

The hypothesis states, the higher technology input sector, namely production of electronic and industrial machinery will grow faster and benefit most from the input demand change of the electricity producing sector, compared to the other sectors that produce for the electricity producing sector. Also, natural gas demand declines as it is replaced with coal; however, coal demand stays flat as well, since it is imported.

2.2 Clean coal project: carbon certificate pricing

The second study estimates abatement costs for different power plant technologies per electric energy unit produced compared to two base technologies, old and new clean coal technology. LCOE per kilowatt-hour (kWh) are calculated for the proposed clean coal power plants in southern Thailand and other Thai electricity producing power plants, like combined cycle (CC) gas, nuclear power, and renewables like wind, solar and biomass power plants. Direct carbon dioxide (CO) emissions are attached to these power technology types. The ratio of the differences in costs and emissions are then estimated. The results show a comparison on how much carbon needs to be priced at in order for a unit of electricity of a cleaner power plant type to be economically as viable as the polluter option. This carbon certificate price where EGAT is indifferent between the old or new clean coal power plant and the other technology is called the mitigation cost of carbon emissions. A benchmark to compare these carbon certificate prices is the European Union (EU) Emission Trading Scheme's (ETS) carbon price. The results could be used by policy makers to support decisions on what technology mix to use, or on how expensive a change in the power development plan may be for the country. The rankings could also be used by the policy maker to explain its constituency why certain types of technologies are used over others.

The actual research question asks, how much does a carbon certificate need to be valued at in Thailand in order to make power plant technologies, renewables especially, economically equal to old and new clean coal power plants and how do these prices compare to the EU ETS?

The objectives are to first calculate the LCOE for a range of power plant technologies in Thailand, and to collect data on these technologies' direct carbon dioxide equivalent (CO_2e) emissions. Furthermore, to estimate and analyze values of carbon abatement costs of each power plant technology used in the study versus the two clean coal base power plants. And finally, to compare the resulting prices with the discounted EU ETS carbon certificate price.

The hypothesis states, the carbon certificate prices identified will be higher than that of the EU ETS.

2.3 Feed-in tariffs for solar energy in Thailand

The third study estimates the costs of different scenarios of accumulated solar power generating capacities that are subsidized with the newly introduced solar FiT in Thailand, for three types of solar power plant sizes. The costs are displayed using Thailand's fuel adjustment mechanism Ft in per electric energy unit per year. The business-as-usual (BAU) scenario is where the power mix constructed follows Thailand's Power Development Plan 2015 (PDP2015). The other scenarios are, no additional solar power, boom, and medium increase in solar power installed. The fuel adjustment mechanism is calculated by adjusting for the price of the solar FiT and the lower costs from the replaced power technology, either old or new clean coal or natural gas. The results of prices could be used by the policy maker to adjust the subsidy program, if deemed appropriate, or to incentivize certain solar power types over other types. General conclusions on where the price of solar power is heading to can also be used by policy makers around the world.

The actual research question asks, how much could the electricity consumer save yearly by replacing the solar power installations with clean coal? Also, by how much will actual and discounted yearly electricity prices increase for more solar power installations by 2036, replacing other technology generation capacity with solar power, calculating the results once with and once without incorporating lower FiT rates for new solar power installations over time?

The objectives are to first assign each yearly capacity additions to fuel types and to divide the yearly renewables additions into solar and other renewables. Also, to define the different scenarios. Then, to collect the levelized costs of power plants from the second study, to then calculate the learning rate based on the scenarios. Furthermore, to calculate the energy generated per fuel in the different scenarios, to then calculate the adjustment mechanism value for each year. Lastly, the results are compared to the BAU scenario.

The hypothesis states, the electricity produced by clean coal power plants will be cheaper than that of renewable power plants. Also, the case where the FiT is reduced over time limits the subsidy payments in the program, whereas in the other case, the subsidy payments may increase significantly over the BAU case. Finally, the subsidy payment may decrease over time in the FiT reduction case, since that FiT will become cheaper at some point than the costs saved by the replaced power plant.

Section 3

3 Justification of the topic of research

In this section, the motivation and reasoning are laid out. There are two parameters, Thailand, southern Thailand respectively, as the research area, and clean coal power plant technology, as the research interest in all three studies. Thailand seems to be the obvious choice, since the research is done in this country and clean coal is of current interest, since the policy maker would like to build a power plant of this type, but the fuel type has gotten a bad name in the climate change discussion. Other additional justifications of the topics include, why a power plant is chosen, why Thailand, or southern Thailand in particular is selected, and some definition on the scope of the thesis are given.

3.1 Large scale project and lasting positive external shock

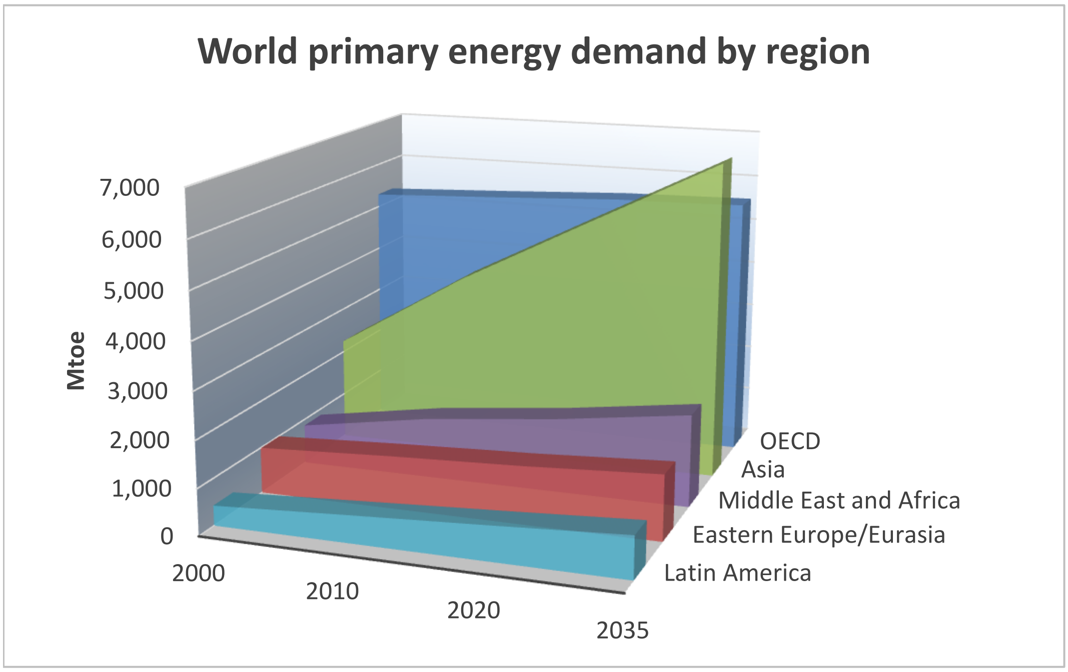
The first study tries to value a substantial externally induced shock to a region. This shock is induced by a large-scale project paid by a central government, state-owned enterprise or from a public-private partnership. The project should be large enough compared to the regional gross domestic product, but small enough to not have any effect on either the national or the regional taxes. There are several large-scale projects within a country or in cooperation with other countries. Some projects are rather intangible, like faster bureaucratic execution of, for example, a firm registration or an issue of an import license. The first study however, tries to value the impacts of a tangible project like infrastructure projects. It could either be a greenfield development project or a significant extension to an already existing structure. To have a lasting shock, the investment project should have large operation and maintenance (O&M) costs after the end of the construction period.

A commercial-scale power plant fits this description very well. It is a large-scale project in nature and usually the funding comes from an external source. Hence, no crowding out effect for the regional business community. In Thailand, the main public power provider EGAT gets some of its resources from the Ministry of Finance (EGAT, 2012). Starting last year, EGAT has appointed a Thai bank to set up an infrastructure fund (Siam Commercial Bank, 2013). The Infrastructure Fund invests in the right to availability payments of the North Bangkok Power Plant Block 1 for 20 years. Its purpose is to fund EGAT's power plant and transmission line construction. In addition, the power plant had yearly operating costs. The Kemper County Energy Facility in the United States (US) is a 582 megawatt (MW) electric power plant with integrated gasification combined cycle (IGCC) and CCS. According to the company, it will create over 1,000 permanent direct and indirect jobs (Kemper County Energy Facility, 2014). Consequently, the Thai power plant will also have indirect effect on the local economy.

3.2 Economic scope

For practical use of the research project, the power plant location needs to be defined. There are various scopes to look at. New power plants are being built all over the world; however, it is of more interest to do research on the region that has the highest expected future energy demand increases. In Figure 3-1 Figure 3-1below, the developed nations in the Organisation for Economic Co-operation and Development (OECD) have the highest energy demand until around the year 2030 when the Asian region, excluding Asian OECD countries, overtakes the OECD members. The developing nations in the Asian region experience the most substantial demand increase for energy compared to other regions in the world, hence, Thailand as a developing county in Asia for the site of the power plant is chosen (The World Bank, 2012).

Figure 3-1: World primary energy demand by region



Source: International Energy Agency (2012)

Thailand is a sensible choice, since next to almost doubling its installed capacity by 2036, Thailand is already the second largest energy consumer in the Association of Southeast Asian Nations (International Energy Agency & Economic Research Institute for ASEAN and East Asia, 2014) and it has a centralized agency for power generation, called EGAT, which has access to a large pool of data. Furthermore, Thailand is an upper middle-income country (The World Bank, 2014b) and after launching its infrastructure fund in the second quarter of 2015 (Reuters, 2015), EGAT has large resources to execute its power development plan, which also includes the construction of new clean coal power plants. The results of this research may be applied to other upper middle-income countries, or other, lower developed countries that are climbing up the ranks of economic development and will find itself on a similar income level in the near future. There are currently almost 6 billion people living in low, lower-middle and upper-middle income countries (The World Bank, 2013), which is more than three quarters of the world population.

3.3 Power development plan

In most countries, governments usually have power development plans of the near future. EGAT together with the Energy Policy and Planning Office (EPPO) has formulated a detailed plan about the future development of the Thai electricity demand and supply (EPPO, 2012). It expects large increases in almost all sources of electric power. The plan also lays out how the country and its economy will advance. It projects the future power demand from the future composition of the economy, its growth rate and subtracts advances in electricity saving technology in the years 2012-2030. Further, the plan illustrates how EGAT will expand its supply of electricity to consumers in order to keep up with its demand. Many power sources are considered, including gas, coal, renewable energy power plants and electricity imports from neighboring countries, mainly the Lao People's Democratic Republic and Myanmar. Some power will come from independent electricity power supplier. The total production of electricity power will more than double from 32,395 MW to over 70,000 MW.

Table 3-1: Total planned capacity changes in Thailand until 2030.

Total capacity in Thailand (incl. imports)	MW
Starting capacity as of December 2011	32,395
Total added capacity 2012 - 2030	55,130
Total retired capacity 2012 - 2030	-16,839
Final capacity as of December 2030	70,686

Source: EPPO (2012)

3.4 Power source

Another important deciding factor for a power plant is the power source. The electric power produced should be economical and have a minimum effect on the environment and the people in the surrounding area. In addition, the fuel should be considered as a fuel that will still be used in the near to middle term future as the lifetime of a power plant is around 30 years but may last longer depending on the amount of maintenance done.

Power plants have different kind of fuels and these fuels have different costs. A study by Wangjiraniran and Euaarporn (2010) makes assumptions on the LCOE in Thailand results in coal being the second cheapest, right after nuclear power. Electricity production using gas comes in third and wind last. The costs consider the lifetime cost of the power plant, which means initial investment, operation and management, fuel cost and an interest rate. For the US, China and India, coal is the cheapest power source. In the EU, it is trailing other sources, as it is highly taxed. In addition, depending on the technology used in a coal power plant, its cost may be higher too. The power plants that use CCS are less efficient and need additional investment. In order to find out how much a carbon certificate would need to be priced at is researched the second study. This will also determine the cheapest option for Thailand.

Another study by Wangjiraniran et al. (2013) compares different future scenarios of energy production. It shows that the scenario that does use coal power plants will end up the cheapest, but also the one that emits the most amount of CO_2. Hence, it may be the most disruptive power source for the local community in terms of air quality. In the last couple of years, however, a lot of research has been done to mitigate the negative effects of the extensive CO_2 production, respectively to decrease its production per kWh produced. Using flue gas desulfurization to reduce the discharge of sulfur and other processes to reduce nitrogen pollutants as well as particulate matter to the air are called clean coal technologies. The name is a bit misleading, as the newer technics do not render coal burning clean, but rather less harmful. There are different ways to achieve that and EGAT divides them up into three different stages. At the pre-combustion stage, a higher grade coal that has a high carbon count is used to simply make the plants more efficient in turning coal to energy. At the combustion stage, a modern technology plant is used, for example, an IGCC plant. Lastly, at the post-combustion stage, the latest technological advancements may be used to store the pollutant CO_2 below ground in a storage site, called CCS, or to use it for enhanced oil recovery to extract more oil from an oil field, called carbon capture, utilization and storage (EGAT, 2015b).

Another important factor concerning the fuel choice of a power plant is the future price of that fuel, its availability and some social acceptance projections. The future price and the availability of the fuel are somewhat interlinked. The more reserves and resources are available, the lower the future price increases. The Federal Institute for Geosciences and Natural Resources (2013) forecasts that coal will continue to play a significant role as an energy supplier and that there are adequate reserves and resources for many decades to come. Natural gas does also have huge reserves and resources, but by far not as much as coal; and crude oil production is probably not able to keep up with possible future demand increases. Further, the World Bank (2014a) projects that the coal price will stay flat around US$80 in real 2010 US dollar for Australian coal until 2025.

The third important factor concerning the future of an energy source is its acceptance in society. The support for nuclear energy for example dipped globally, especially in Europe but also in Thailand, after the Fukushima accident (Aldrich, 2011). Coal, like other fossil fuels also raises public concern as the combustion of it harms the environment and contributes a lot to climate change, around one third of man-made CO_2 emissions come from coal burning (Greenpeace, 2014). Policymakers, energy producers and engineers that are in favor of coal because of its reliance, availability and low cost are aware of the social costs and that the public wants cleaner energy. Hence, as in the last paragraph, technologies that are more efficient are introduced to make the processes around the combustion cleaner and diffuse public concern.

3.5 Location within the country

Another important deciding factor for the location of the power plant is the power source. There are different scopes that need to be covered. First up, a power plant should be built near where the raw material is recovered that feeds it, respectively at a location where the power source can be cheaply transported to. Hence, for my research I want to study the impacts of the power plant at a very probable location in Thailand and EGAT (2013a) states in its PDP2015 that the next clean coal power plant will be built in the Krabi region. The Krabi clean coal technology power project will be built as an extension to the existing Krabi power plant. The launch is planned for June 2019 and the contracted capacity is 800MW. There are three more coal fired plants planned for 2022, 2025 and 2028, each with a capacity of 1000MW. The same is true for gas power plants of which several plants are going to be constructed in the 2015-2036 period. The coal burnt in the Krabi clean coal plant will be a higher-grade coal than what is available in Thailand, which is mainly lignite; hence, it is imported by ship from abroad, South Africa, Indonesia and Australia (Techawongtham, 2014).

3.6 Pollution

The impact also includes intangibles like the environment; those effects can be valued with the market prices for the coal pollutants. Some of the climate harming pollutants include CO_2, sulfur dioxide (SO_2) and mono-nitrogen oxides (NO_X). There are markets for these pollutants in Europe and the US. The first study analyzed the impact of the power plant on the economy, neglecting the negative effects of pollution. However, a more detailed assessment on carbon equivalent emissions and possible carbon certificate prices are investigated in study two. Study three is also neglecting emissions, but it relates high-emission coal technology to solar PV power and estimates a subsidy price in order to replace some of the future coal energy demand.

3.7 Tools

The calculations for this thesis are mostly done in Microsoft Excel, however, some computations are also done in FoxPlus, R (R Development Core Team, 2016), and Python (Python Software Foundation, 2018) in a Jupyter Notebook (Kluyver et al., 2016). The code in R and the Jupyter Notebook are found on Github, in the repository ccasimiro9444/papers (Odermatt, 2018). It mainly features the sensitivity analysis for regional impact study, and the data on yearly power additions per fuel and producer type for the solar FiT study.

The studies and the thesis are all written in Microsoft Word.

3.8 Definitions

This thesis uses certain terms over all three studies in sections 4-6, thus, those terms are defined here. Other definitions that relate to one of the studies only, are defined in the specific literature review section of that study.

Clean coal technology

Throughout this thesis clean coal technology is mentioned. Clean coal technology basically means that a mechanism is in place to desulfurize the flue gas to minimize the release of sulfur in the exhaust (Vongmahadlek & Vongmahadlek, 2016). It is usually mentioned in tandem with highly efficient, or ultra super-critical, coal power plants that have further systems in place to reduce other kinds of greenhouse gas (GHG) emissions farther (Franco & Diaz, 2009). This may entail a higher-grade coal quality as well (Özbayoğlu & Mamurekli, 1994).

Old and new clean coal power plant

The two clean coal power plant types in this thesis are an old clean coal technology and a new type of clean coal technology. In Thailand, the former relates to units 4-13 at the Mae Moh coal power plant in Lampang province (EGAT, 2013b). It is of sub-critical efficiency, at around 35%, and the fuel used is lignite, which has a low calorific value, meaning that lignite's heating value is low. The new clean coal technology is a state-of-the-art new clean coal power plant, similar to the Schwarze Pumpe power plant in Brandenburg, Germany. That plant's unit efficiency is higher than 42%, and also uses lignite to generate electric energy (Leĭzerovich, 2008). The new clean coal power plant in this thesis uses a clean coal power plant run with bituminous coal tough. This means that it can be a bit more efficient, it will also pollute less, but has higher fuel costs.

EGAT, and the framework it operates in

EGAT is a state enterprise managed by the Ministry of Energy (Department of Energy Business, 2010). It that has the authority to produce and transmit electric power, the current plan is the PDP2015 (EPPO, 2015c). EGAT executes EPPO's power development plan. There are also small and large independent electricity producers in Thailand, they must sell their electric energy to EGAT for transmission. The distribution to the consumer is done by the Metropolitan and Provincial Electricity Authorities, and to a lesser degree by EGAT as well (Energy Regulatory Commission of Thailand, 2012). The distribution and tariff structure are regulated by the Energy Regulatory Commission. The tariff also includes the fuel adjustment mechanism Ft (Energy Regulatory Commission of Thailand, 2010). EGAT is also a large data aggregator. The website is in Thai and often also in English. Data on current power plants and projects are found on their site as well as energy related news and most importantly data on energy production, consumption, and carbon emissions. Furthermore, data related to the Ft and tariffs are also featured, however, mostly in Thai (EGAT, 2018).

EPPO and the PDP2015

EPPO is a dependent department at the Ministry of Energy (EPPO, 2016a). EPPO and EGAT periodically produce a power development plan. The current plan is the PDP2015 (EPPO, 2015c) which is the Ministry of Energy's strategy for the next 21 years, starting in 2015. The previous plan was published in 2012 in its third version (EPPO, 2012). The PDP2015 is publish along with other strategic plans, the plans being the Energy Efficiency Development Plan (EPPO, 2016d), the Alternative Energy Development Plan (EPPO, 2015a), the Gas Plan (EPPO, 2016b), and the Oil Plan (EPPO, 2016c). The development plan includes details on the commissioning and decommissioning of power plants per fuel type, ownership type, and year. Thus, the third study relies highly on the PDP2015. Furthermore, the plan also discusses the clean coal power plants to be built in southern Thailand, hence, it is also used for the first study. Lastly, the PDP2015 is also used for the second study in conjunction with the Alternative Energy Development Plan, in order to decide which renewable energy technologies are going to be built in Thailand and by what capacity.

Section 4 – Study 1

4 Clean coal power plants and their regional economic impact

4.1 Abstract

A new clean coal power plant is proposed to be built in Krabi, Thailand, to produce electricity for the increased electricity demand of the country’s south. Currently, most parties involved in the project are looking at the possible environmental damages, but not looking at a possible transformation of the input shares of the economic sectors. The economic impact of the power plant units on the economy of southern Thailand are analyzed. The study examines how inputs into the electricity producing sector transform after the proposed clean coal power plant has been built and which sectors will benefit most in terms of demand from the electricity producing sector. The findings, if the clean coal power plants have been constructed as planned, show that in terms of relative input change for the electricity producing sector, the electricity producing sector would benefit the most, using German clean coal technology, as well as the electrical machinery sector; while there would be a stark decrease in demand for natural gas. In absolute terms, business services related industries, trade related services, public works and the previously mentioned sectors, namely the electrical machinery and the electricity producing sectors, will see the most demand increases. IO tables are used to estimate these changes in the input demand for the electricity producing sector with data from the respective countries’ national statistical offices. The standard location quotient regionalizes the German and Thai national IO tables, for Brandenburg and the southern Thai provinces respectively. The study may be used for regional policy purposes in southern Thailand.

4.2 Introduction

This section calculates the sole economic impacts of EGAT's forthcoming clean coal power plant in Krabi on a cluster of provinces around Krabi province (EGAT, 2013a). Doing this provides answers on how the economy in that region will transform from the additional investment, suggesting there may be a stark increase in regional demand for inputs into the clean coal power plant, especially for machinery and the electricity sector itself. The results may be applied for similar projects in Thailand and other countries with similar characteristics. This study uses IO tables to assess the economic impact. IO tables provide a micro level tool to measure or forecast public investment programs. Hence, various regional development studies can be undertaken with IO tables and the results may then be used for policy recommendations. The government bodies could perhaps show that even though the investment may harm the environment, it may provide income growth in these provinces. The forecast that this study produces should be compared with the real outcome after the construction in order to assess the forecast and its methods; and to amend the forecasting method to construct a more precise forecast the next time. In addition, a specific method will be defined on how to transform the national IO table to the assigned regions in Germany and Thailand. This method could be used to construct other regional IO tables in Thailand.

The proceeding sub-section of this section embodies the literature review, specifies the data sources and states some issues. The fourth sub-section illustrates the model used, while the fifth presents the results. In the last sub-section, conclusions to this section are drawn and possible next steps listed.

4.3 Literature review

The definition of a clean coal power plant can vary a lot. The words clean coal power plant may also be misleading as the power plant is not really clean in that no polluting emissions are produced, but rather that these pollutants are either reduced substantially or will not be discharged into the air (The National Mining Association, 2016). In the context of this research, we are referring a clean coal power plant to a high-efficiency, low emission coal power plant without CCS. A model for the Krabi clean coal power plant is the Schwarze Pumpe clean coal power plant in Brandenburg, Germany. For this research, we are assuming no crowding out effect for the regional business community, since in Thailand, the main public power provider, EGAT, gets its resources from the Ministry of Finance (EGAT, 2012). Also, in 2013, EGAT has appointed a Thai bank to set up an infrastructure fund (Siam Commercial Bank, 2013). The infrastructure fund invests in the rights to availability payments of the North Bangkok Power Plant Block 1 for 20 years. Its purpose is to fund the construction of EGAT's power plants and transmission lines (EGAT, 2015b).

EGAT plans to build three clean coal power plants in the southern part of Thailand. Hence, this research concentrates on these provinces. The regional IO table for these provinces are adjusted with the technological coefficients of Brandenburg, Germany. This region is selected, because it hosted the first CCS power plant in Germany, actually, it is one of the oldest CCS power plants built. The power plant is called Schwarze Pumpe and was a pilot plant for Vattenfall Europe AG and did have its groundbreaking ceremony in May 2006 (Vattenfall, 2012). Furthermore, there are other high-efficiency, low emission power plants in the state of Brandenburg (Altmann, 2006) and coal accounts for more than 75% of the electricity produced of power plants larger than 50MW in this state (Bundesnetzagentur, 2016).

Table 4-1: Total installed power in southern Thailand and Brandenburg, power plants >50MW, in 2015 and 2011 respectively.

Southern Thailand	in MW	in % of total
Total	2,377	100.00
Natural gas	1,725	72.57
Fuel oil	340	14.30
Water	312	13.13

Brandenburg	in MW	in % of total
Total	5,728	100.00
Natural gas	364	6.35
Fuel oil	212	3.70
Wind	788	13.76
Coal	4364	76.19

Source: EPPO (2015c), Bundesnetzagentur (2016)

The first Thai clean coal power plant is projected to be built in Krabi town on the existing oil power plant site. As two more coal power plants are projected to go online in the south, this research concentrates on the southern provinces. The regional IO table is therefore constructed for these provinces, namely Phuket, Ranong, Phang Nga, Krabi, Trang, Surat Thani, Chumphon, Nakhon Si Thammarat, Phatthalung, Songkhla, Satun, Yala, Narathiwat and Pattani (Office of the National Economic and Social Development Board, 2016a).

Table 4-2: Provinces in southern Thailand.

Provinces	
Phuket	Nakhon Si Thammarat
Ranong	Phatthalung
Phang Nga	Songkhla
Krabi	Sathun
Trang	Yala
Surat Thani	Narathiwat
Chumphon	Pattani

Source: Office of the National Economic and Social Development Board (2016a)

For the regional tables in Germany and Thailand, a non-survey method that uses the top-down approach is chosen. The non-survey method applied uses some mathematical procedures and secondary micro data about the regions. The secondary data datasets are available online from various government agencies in both countries, but mainly the National Statistical Office (2016) in Thailand and the Federal Statistical Office (2016) in Germany.

There is an extensive and long running literature on the IO methodology. Wassily Leontief (1941) created the concept of these tables for the American economy in the first half of the 20th century, and discussed its multipliers, the usefulness of a microanalysis, and some of its problems in many papers in the following years (Leontief, 1949) and (Leontief, 1952). The IO model is mainly used to analyze the dependence between each sector in the economy (Miller & Blair, 2009). The table tries to answer how much of each production factor, intermediate good respectively, is used in the production of either another intermediate or a final good. These input values can be converted into ratios of their total inputs, called technical coefficients, and we can then calculate each input's impact on total output (Yan, 1969). Since Leontief's first modeling approaches, many economists around the world used and improved the IO concept and, nowadays, almost all countries construct one national IO table every couple of years. In the case of Thailand, a national IO table is constructed every five years, while in Germany, an IO table is generated once per year.

A couple of years later, Isard (1953) and Moore and Peterson (1955) attempted to construct IO tables for sub-national spatial units in the US. Most sub-national IO tables are derived for the state or provincial level (Sargento, 2009). The national IO table is constructed by collecting survey data; regional IO tables can also be devised in this manner. Constructing an IO table through a survey, regional or national, is expensive and time consuming, hence only a handful of countries do this on the regional level. Canada does not directly compile regional data, but constructs tables with inter-regional trade flows which allows for the generation of balanced regional IO tables (Genereux & Langen, 2002), while China offers computed multi-regional IO tables since 1997 (Yaxiong & Zhao, 2009). In the US, several regional economic modeling software tools exist to construct regional IO tables (Hendrickson, Lave, &

Matthews, 2006), for example the Regional Industrial Multiplier System by the Bureau of Economic Analysis (2015) and two commercially available tools by the Regional Economic Models, Inc. (2016) and by Impact Analysis for Planning (2016). In the case of Thailand, the office in charge of compiling IO tables, the Office of the National Economic and Social Development Board (2016b), does not construct regional IO tables, nor any kind of inter-regional trade flows. Furthermore, there are also no private companies that construct such tables. Hence, this study deduces a regional IO table for the southern region from the national IO table.

The latest Thai national IO table was published in December 2015; it represents the year 2010. In order to assess the change of inputs into the electricity producing sector, an updated IO table for Thailand and a regional IO table of Brandenburg, Germany, and of Thailand's south needs to be created. The national Thai IO table was updated for the year 2015 using the RAS method. This is the latest year where detailed gross domestic product data is available. The RAS method is a mathematical technique to update any IO table. There are different ways to use the method and the technique goes back to Stone (1961). The RAS method updates the IO table by applying gross domestic product data from a different year together with the total output data. These columns then create two vectors, R and S. Those vectors then update the matrix of the technology coefficients, called the A matrix. Another approach is shown by Toh (1998) who projected the Leontief inverse directly from its base year inverse. Toh's method's advantage is that the matrix used for computation is denser as there are less cells containing the value zero; however, he admits that in the end his method is not superior to the traditional RAS method. Hence, the traditional RAS method is chosen for this study. Thailand, or EGAT respectively, will be importing a lot of coal, from Indonesia, Australia and South Africa (Sarnsamak, 2014). These imports, as the word literally says, are not demanded from the domestic Thai economy. So, they are not of interest for this study which estimates the changes in goods and services inputs into the electricity sector in southern Thailand. Hence, we neglect these imports for the RAS method. Furthermore, the RAS procedure only works on a square matrix, hence, only the intermediate transaction value matrix is chosen.

The RAS method adjusts the 2010 Thai national IO table to the 2015's economic condition, however, it does not yet adjust for any price changes. Hence, Thailand's producer price index changes from 2010 to 2015 are calculated and inserted to account for the effect of inflation (Meade, 2007). The method used to correct for the inflation is to get each sectors' producer price changes. The Thai data does not feature producer prices for services, hence, inflation values of the consumer price index are assumed.

In order to derive the regional IO coefficients for southern Thailand this study uses a localization technique. There are a few different methods to estimate the local technical coefficients. The most used technique may be the simple location quotient method which is a non-survey technique using only mathematical procedures, it goes back to Haig (1926). Others are a gravity model and regression equations (Deng et al., 2014), the Flegg location quotient (Flegg & Webber, 1997), the commodity balance approach, and the cross-hauling adjusted regionalization method (Kronenberg, 2009) where some try to adjust for cross-hauling to different degrees. By using a location quotient, it is assumed that the national and the regional economies' technical coefficients are similar in each country separately, hence there are no sectoral clusters in a province that may have a technological advantage over the whole country. Wassily Leontief (1949) found that this is the case, even after comparing technical coefficients of different countries. Yan (1969) makes the same assumption; hence, there is no problem applying it for this study as well. In the case that there is no data to regionalize the IO table, the national technology assumption may be used as well. The national technology assumption sets the local coefficients equal to the national values, as it assumes the coefficients to be spatially invariant within a country (Lahr, 1993). Jensen-Butler and Madsen (2003) justify this assumption as at high disaggregation of sectors in an IO table, the hypothesis is not very restrictive. This study however uses a hybrid technique, the simple location quotient method, with some adjustments after the mathematical procedures. The simple location quotient uses the ratio of two employment ratios, specifically the employment in a sector in a region over total employment of that region divided by the same ratio, but on the national level (Miller & Blair, 2009). It is a widely accepted method and with the data for Thailand on hand, the preferred technique. This means we are not adjusting for cross-hauling between the southern region and the rest of Thailand and we are assuming identical technology levels for the whole country and neglect subsidies and transfers. The location quotient method is not without its faults. Mills (1993) describes that in a regional IO table, the role of government debt and its budget constraints are not considered. Hence, the regional IO table may overstate the benefits of spending by the government. In our case however, EGAT will pay for the project, not the regional government, therefore we can dismiss this issue. Also, Richardson (1985) points out that the derivation of the local share of spending may not be very exact when done on a non-survey basis, while others identify the issue with interregional and international trade for these spatial sub-units. In order to address this issue, researchers use hybrid models that incorporate available superior regional data. Survey-methods may be superior but also not without problems. Questions may not be answered by all participants or may be filled out incorrectly. Hence, a hybrid method is usually preferred and is also used in this section. Therefore, if better information for a sector was available, the technical coefficient was replaced. Furthermore, the model of the IO table imposes the assumption that EGAT will use the same clean coal technology as it existed in Brandenburg's power plants in 2011.

This study estimates the changes in input for the electricity producing sector from the other sectors in the economy of Thailand's southern provinces. EGAT replaces a small sized oil (EGAT, 2016c) power plant with a larger clean coal power plant and will add two more units in the following years. There may be negative environmental impacts on the immediate surrounding area. However, as the coal power plant is built to be clean, it will emit a minimal amount of climate harming pollutants, including CO_2, SO_2 and NO_X. Furthermore, contrary to the Mae Moh coal power plant in northern Thailand, the new power plant units are not surrounded by mountains and no temperature inversion can occur that would trap the SO_2 and NO_X (Leightner, 1999). Therefore, I will neglect direct effects of pollution or a carbon price. Lastly, in the case for Krabi, EGAT will build a tunnel for the last stage coal transport to minimize the harm done to the local environment and landscape. Hence, I assume no additional harm is done to the environment, this assumption could be relaxed in further research.

The calculated RAS table for Thailand for 2015, the regional IO tables for Brandenburg and southern Thailand, as well as the updated regional tables with the new column for the electricity sector inputs are tested with a sensitivity analysis. There are different possible mathematical procedures to test for a matrix' sensitivity.

Sonis and Hewings (1995) extended their previous work and proposed changes in a matrix for sub-matrices of the matrix. Their mathematical procedure was created to calculate sensitivity analysis of multi-region multipliers. They measure a matrix after simultaneous changes in different blocks. In this study, however, we only change one column. Hence, another method is used for the matrix sensitivity analysis. The proposed technique by Wolff (2005) relies solely on mathematics without the need to apply any assumptions. It uses a measure of robustness for the whole IO matrix after the change. Hence, we can compare the initial inverse of the spectral condition number (Wilkinson, 1988) with the new measurements of the updated matrices. If the matrix, depending on its size, has a certain magnitude, then the matrix is robust.

4.4 Model

This study uses an IO model to estimate the input demand changes of the electricity sector after the clean coal power plant has been built. An IO model, according to the Bureau of Economic Analysis (2015) at the US Department of Commerce, is a tool used by government planners to assess the potential economic impacts of various projects. The multipliers resulting from the study may be used in an economic impact study to estimate the total impact of a project on a region; the total impact being the direct and indirect economic contribution.

In order to update the electricity demand column for the southern Thai region to account for a change in inputs, I had to make the German and Thai tables compatible first. The German national level IO table (Destatis, 2015) has 71 sectors while the Thai national IO table (Office of the National Economic and Social Development Board, 2016b) is much larger with 180 sector divisions. Both countries use the Classification of Products by Activity but the German table uses some adjustments, therefore, the two countries' sectors could be matched together quite well (Tang, Gong, Liu, & Li, 2015). The final unified sector classification had 43 distinct sectors, where sector number 24 was the electricity producing sector. This produced two consolidated IO tables; one for Germany in 2011 as well as one for Thailand in 2010.

The Office of the National Economic and Social Development Board recently published the Thai national IO table for 2010. Hence, I needed to update a Thai national IO table for the most recent year possible, which is 2015. In order to compute a 2015 Thai national IO table, the RAS method is used. The RAS method uses two vectors, turned into their respective diagonal matrices $\hat{\boldsymbol{r}}$ and $\hat{\boldsymbol{s}}$, to update the IO table, the $\boldsymbol{A}$ matrix, where the $\hat{\boldsymbol{r}}$ matrix pre-multiplies the matrix and the other diagonal matrix post-multiplies it. The hat defines henceforth a diagonal matrix consisting of the vector below the hat, as in $\boldsymbol{ri}' = \hat{\boldsymbol{r}}$. By ignoring the hats and the lower case of the letters, this can be written as $\boldsymbol{RAS}$. The RAS procedure can only be computed with a square matrix. This means that we can update the technological coefficients for each of the sector pairs, meaning each intermediate input; but we cannot update the separate final demand components of the gross domestic output, namely consumption, investment, government purchases and net exports (Miller & Blair, 1985). Similarly, we cannot update the input coefficients for labor, tax and value added. The RAS procedure needs four pieces of information, (i) the technical coefficient matrix from the base year, (ii) the gross domestic product figures for the target year, (iii) the total interindustry sales for the target year, and (iv) the total interindustry purchases for the target year. The gross domestic product figures for the target year are divided up into 16 sectors, so I have to assume that, for example, most manufacturing sectors in the IO table grew at the same rate, furthermore, I also assume that imports grew at the same rate for each sector (Bank of Thailand, 2016). Now, we use an iterative process to calculate the vectors, with which we can update the IO table. We are using the naming convention similar to Miller and Blair (2009), see Table 4-3 below.

Table 4-3: Variable description for RAS procedure.

$\boldsymbol{A}(c)$	$\boldsymbol{A}$ stands for the technical coefficient matrix, $n\ x\ n$ square matrix
c	c stands for the number of iteration on $\boldsymbol{A}$ and $\boldsymbol{Z}$ matrices
d	d stands for the number of iteration on the $\boldsymbol{u}$, $\boldsymbol{v}$ and $\boldsymbol{r}$, $\boldsymbol{s}$ vectors
n	Number of sectors, $n = 43$
$x_{i,j}$	Total gross output or input of a sector
i, j	Respective sectors, i are the row and j the column sectors
z_{ij}	Inputs and respective outputs of production per sector (intermediates)
$\boldsymbol{Z}(c)$	$\boldsymbol{Z}$ stands for transaction matrix, $n\ x\ n$ square matrix
u_i	Total interindustry sales
v_j	Total interindustry purchases
r_i	Adjustment terms for the total interindustry sales values
s_j	Adjustment terms for the total interindustry purchases values

First, we need to define the target year vectors. We have the $\boldsymbol{u}$ and $\boldsymbol{v}$ vectors, as $u_i(d) = \sum_{j=1}^{n} z_{ij}\,(d)$ and $v_j(d) = \sum_{i=1}^{n} z_{ij}(d)$, where we have $\boldsymbol{u}(d) = \begin{bmatrix} u_1(d) \\ \vdots \\ u_n(d) \end{bmatrix}$ in its vector form, and $\boldsymbol{v}'(d) = \begin{bmatrix} v_1(d) \\ \vdots \\ v_n(d) \end{bmatrix}$ respectively. The parameter d refers to the iteration done for each vector, starting with $\boldsymbol{u}$. Additionally, we are also using the $\boldsymbol{x}$ vector, which is $x_i = \sum_{j=1}^{n} z_{ij} + (gdp_i)$ or in vector form $\boldsymbol{x} = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}$, as you can see the gross output is not being altered with each iteration. Gross inputs contain the same values as gross outputs but is a row vector.

With these target vectors, we are now able to use the base year matrix $\boldsymbol{A}$ consisting of the technical coefficients of the 43 sectors from 2010. From the target year 2015 we have $\boldsymbol{u}$ and $\boldsymbol{v}$, which are the sum of intermediate outputs and inputs respectively; and $\boldsymbol{x}$, which is the total gross output.

The iteration process is kicked off by post-multiplying a diagonal matrix $\hat{\boldsymbol{x}}$ with the technical coefficient matrix $\boldsymbol{A}(0)$ which results into an updated transaction matrix $\boldsymbol{Z}(1)$, $\boldsymbol{A}(0)\hat{\boldsymbol{x}} = \boldsymbol{Z}(1)$**.** Using $\boldsymbol{Z}(1)$ we can calculate a $\boldsymbol{u}(1)$ by summing each row as shown above. These new values in $\boldsymbol{u}(1)$ are now divided by the original $\boldsymbol{u}$ values, which are the intermediate output sums for the target year. This procedure generates the first iteration of the $\boldsymbol{r}$ vector, $u_i(1)/u_i = r_i(1)$. The $\hat{\boldsymbol{r}}$ matrix is now pre-multiplied with $\boldsymbol{A}(0)$ to calculate the first iteration of the technical coefficient matrix, $\hat{\boldsymbol{r}}\boldsymbol{A}(0) = \boldsymbol{A}(1)$.

The next step is a similar iteration as before using the newly created values, $\boldsymbol{A}(1)\hat{\boldsymbol{x}} = \boldsymbol{Z}(2)$. The row sums will now equal the actual values of the original $\boldsymbol{u}$ values, as we have adjusted them with the $\boldsymbol{r}$ vector. However, the intermediate input sums $\boldsymbol{v}(1)$ are off compared to the original $\boldsymbol{v}$ values. Hence, we must do the same subsequent step using the column sums to calculate the first $\boldsymbol{s}$ vector iteration, $v_i(1)/v_i = s_i(1)$. The $\hat{\boldsymbol{s}}$ matrix is now post-multiplied with the latest technical coefficient matrix, in this case $\boldsymbol{A}(1)$. This computation provides the second iteration of the technical coefficient matrix, $\boldsymbol{A}(1)\hat{\boldsymbol{s}} = \boldsymbol{A}(2)$.

Now we would repeat the steps to calculate the $\boldsymbol{r}$ and $\boldsymbol{s}$ vectors in the last two paragraphs, always using the latest updated matrix or vector, as in $\boldsymbol{A}(2)\hat{\boldsymbol{x}} = \boldsymbol{Z}(3)$ and so forth until a threshold is reached. The objective may be to obtain $\boldsymbol{u}(d)$ and $\boldsymbol{v}(d)$ terms that are close to the original target terms, as in Miller and Blair (2009). For this study, I am using a threshold that renders small technical coefficient changes from the previous technical coefficient matrix to the next. In order to achieve that, most terms in $\boldsymbol{r}$ and $\boldsymbol{s}$ need to be very close to 1. After the first iterations for each vector, we have many values in $\boldsymbol{r}$ and $\boldsymbol{s}$ that are far off from unity, hence we repeat this process multiple times, alternating between the two vectors, until the defined threshold is met. The threshold used is $\varepsilon < 0.005$ for each cell in the technical coefficient matrix. This was achieved after $c = 14$ iterations, making $\boldsymbol{A}(14)$ our RAS updated Thai national IO table of its coefficients, and $\boldsymbol{Z}(14)$ the updated transaction table.

We can write this in two formulas for the odd and even iterations.

$$\boldsymbol{A}(odd) = \left[\boldsymbol{u}(2015) \Big/ \sum_{J=1}^{n} \widehat{[\boldsymbol{A}(odd-1)\hat{\boldsymbol{x}}(2015)]_{\iota J}} \left(roundup\left(\frac{odd}{2}\right)\right)\right] \boldsymbol{A}(odd-1)$$

$$\boldsymbol{A}(even) = \boldsymbol{A}(even-1)\left[\boldsymbol{u}(2015) \Big/ \sum_{J=1}^{n} \widehat{[\boldsymbol{A}(even-1)\hat{\boldsymbol{x}}(2015)]_{\iota J}} \left(\frac{odd}{2}\right)\right]$$

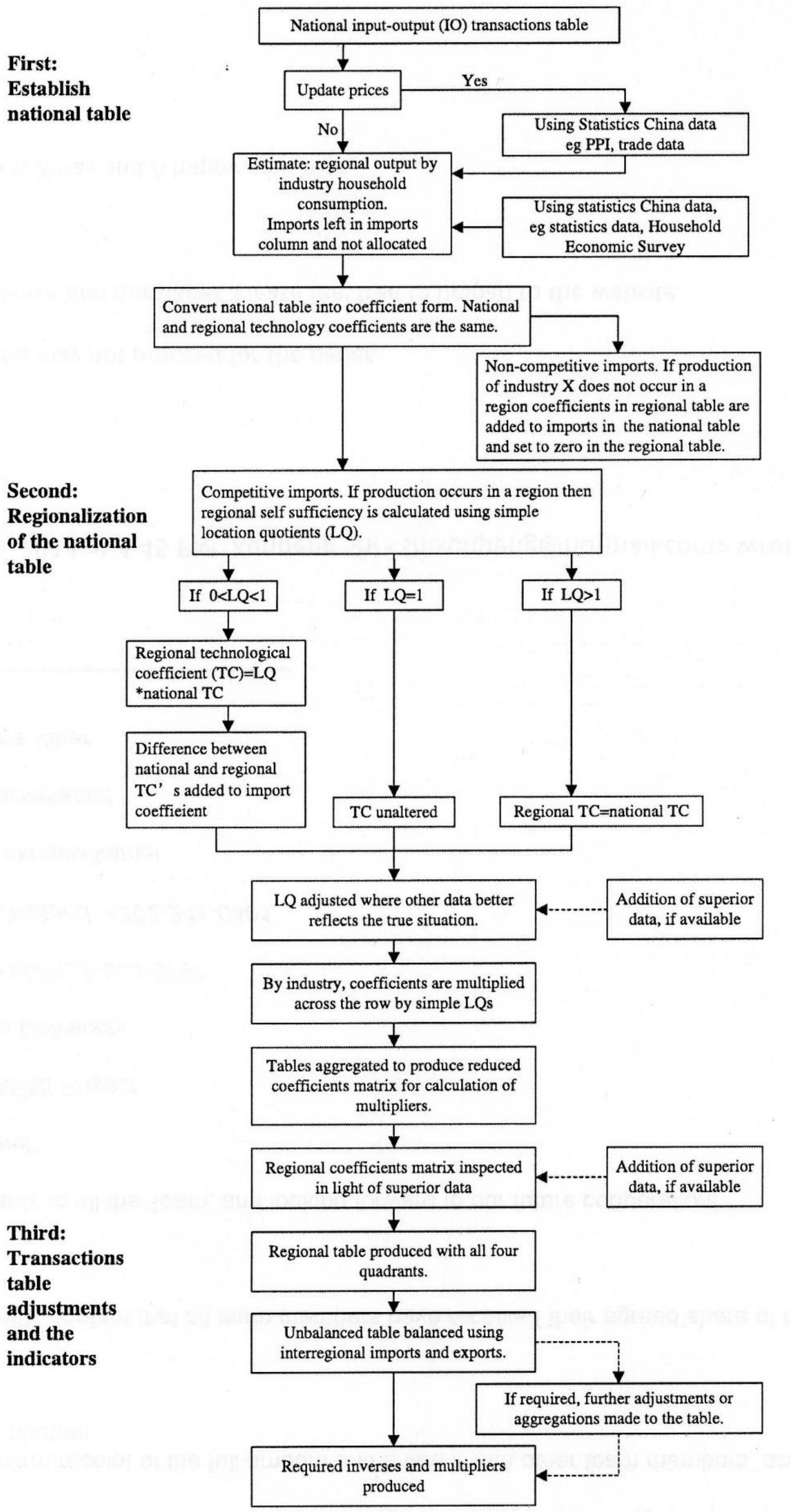
Since we have updated the IO table with 2010 Thai baht, in the next step, the transaction table $\boldsymbol{Z}(14)$ is updated with the 2015 price levels. We are primarily using the producer prices, since the transactions are of intermediate nature; while for some industries that had no producer prices, especially in the services sector, the consumer price index is used.

$$\boldsymbol{A}^{2015} = \boldsymbol{A}(14) * PPI$$

This completed our rendering of the 2015 Thai national IO table. Leaving only the last step where the German and Thai tables are localized to the regions of Brandenburg, in the case of Germany, and southern Thailand, in the case of Thailand.

The construction of the regional IO table for Brandenburg was done according to Deng, Wang, Wu, Zhang, and Li's book (2014), see Figure 4-1 below.

Figure 4-1: Summary of a process to construct hybrid regional IO tables.



Source: Deng, Wang, Wu, Zhang, and Li (2014)

Both countries' IO table are regionalized with a hybrid method consisting of the simple location quotient and superior secondary data. The location quotient is computed for each sector using the labor data ratio in Brandenburg, and southern Thailand respectively. Each ratio is derived by dividing the regional labor ratio per sector by the national labor ratio per sector, according to the following formula:

$LQ_i = \frac{L_i^R/L^R}{L_i^N/L^N}$, with the regional technical coefficient $a_{ij}^R = \begin{cases} LQ_i^R * a_{ij}^N & if\ LQ_i^R < 1 \\ a_{ij}^N & if\ LQ_i^R \geq 1 \end{cases}$

LQ_i stands for the location quotient in sector i, while L_i is the number of workers in sector i with a superscript N or R for national or regional respectively. $LQ_i > 1$ are set equal to unity, this renders no region with a superior technology to the national technology. In other words, the national technology is the best available to all regions.

Some of the sectors were adjusted with secondary data to associate the different regional characteristics. There is a large coal mining sector in Brandenburg that supplies lignite to the regional coal power plants, while in Thailand's south, there is basically no coal. The sub-bituminous and bituminous coal for the power plants in the south are going to be imported from Australia, Indonesia and South Africa (Department of Mineral Resources, 2013). Hence, the intermediate input from the mining sector is set to zero in both regional tables. In the regional IO table for southern Thailand, the oil refineries sector is also reduced to 0, because all Thai oil refineries are in the eastern seaboard of Thailand (PTT Group, 2017). However, there are oil fields in the southern region, ergo, the oil drilling sector keeps its input coefficient as is (Department of Mineral Resources, 2014). Furthermore, the Brandenburg IO table needs to be adjusted more. In order to account for the difference in government regulations and policies, I assumed that public administration input in Thailand's south in 2015 would be the same as in 2010, rather than using Brandenburg's technical coefficient. Moreover, we are using Brandenburg's coal technology, hence, the primary fuel inputs of gas and oil are set to 0 as well. Lastly, the iron and steel input is also set to 0, because this input is usually sourced from a very large production plant, as these plans work on economies of scale

(Crompton & Lesourd, 2008). Hence, this study assumes that there will be no large iron and steel production plant built in southern Thailand. Finally, the electricity columns for both regional tables need to be normalized in order to be comparable.

$$a_{i,24}^{normalized} = a_{i,24} * \left(\frac{1}{\sum_{i=1}^{I} a_{i,24}}\right)$$

These normalized technical coefficients are now called $a_{i,24}^{TH}$ and $a_{i,24}^{DE}$ for southern Thailand and Brandenburg respectively. Thus, in conclusion, the final two formulas to calculate the results of this section are given. First, to answer the research question on what input sectors will benefit most relatively, a new technical coefficient column for electricity for southern Thailand is calculated by subtracting the decommissioned oil power plant and adding the Brandenburg technology, both in terms of their capacity size. The first term after the equal sign in the square brackets does just that, while the second term after the square brackets normalizes the technical coefficient again in order to keep them comparable.

$$a_{i,24} = \left[a_{i,24}^{TH} * \left(1 - \frac{krabi\_mw}{south\_mw}\right) + a_{i,24}^{DE} * \left(\frac{clean\_coal\_units\_mw}{south\_mw}\right)\right] * \frac{south\_mw}{total\_new\_south\_mw}$$

Second, the additional demand for each sector by the clean coal power plant is calculated. This time, the oil power plant is not subtracted from the new input demand of the clean coal power plant to see the sole demand changes from the coal technology. The regional technical input coefficient is multiplied by the size of the power plant, which then in turn is multiplied by the possible local demand from the clean coal power plant. That demand constitutes of the O&M costs excluding its labor therein. For this study, the O&M cost excluding labor are calculated by subtracting the annual fuel, capital, and labor costs from the LCOE and then multiplied by the hours per year and the plants efficiency.

$$z_{i,24} = a_{i,24}^{DE} * clean\_coal\_units\_mw * \left[(lcoe - fuel - capital\_cost - labor) * \frac{hours}{year} * efficiency \right]$$

The resulting technical coefficient electricity columns from the previous step are inserted in the matrix by replacing the existing electricity demand column. These regional IO tables are then run through a mathematical process to calculate a τ value used to compare if the matrices are well-conditioned. Wolff (2005) assumes a value of around 0.07 – 0.14 for a medium-sized matrix with 43 sectors.

4.5 Results

Intermediate results

The first step was to align the sectors for Thailand and Germany. The result is as in the Table 4-4 below. The first couple of sectors are of the agriculture type, then there are some sectors on raw materials production. The next sectors cover manufacturing types. Then there is the electricity sector, sector 24. This sector is studied and replaced in the regional Thai IO table with modern technology. Further are other utility sectors and construction. There are several transport sectors and trade. Lastly, the services, government, education, and health sectors.

Table 4-4: Sector representation after the alignment of Thailand's and Germany's sectors.

Sector number	Sector description	Sector number	Sector description
1	Agriculture, Hunting and services thereof	23	Other Manufactured Products
2	Forestry and services thereof	24	Electricity
3	Fishery	25	Gas, Pipe Line (LPG, natural gasoline NGL)
4	Coal and Lignite	26	Water Works and Supply
5	Petroleum and Natural Gas (Drilling, Exploration)	27	Building Construction and Public Works
6	Metal and Non-Metal Ore	28	Trade, Repair
7	Food Manufacturing, Animal Food, Beverages and Tabacco Products	29	Transportation Land
8	Textile Industry	30	Tranportation Water
9	Saw Mills and Wood Products	31	Transportation Air
10	Paper, Paper Products and Printing	32	Silo and Warehouse and other Services
11	Petroleum Refineries	33	Post and Telecom
12	Chemical and Pharma Products	34	Restaurants and Hotels
13	Rubber Products	35	Banking Services
14	Glass Products	36	Insurance Services
15	Cement and Concrete Products, Ceramic Wares	37	Real Estate Services
16	Iron and Steel	38	Business Service
17	Non-ferrous Metal	39	Public Administration
18	Fabricated Metal Products	40	Eductaion
19	Industrial Machinery	41	Hospital
20	Electrical Machinery	42	Entertainment
21	Motor Vehicles an Repairing	43	Personal Services
22	Other Transportation	-	-

Source: Author

Results

The results stem from the southern Thai regional IO table with a replaced electricity sector input column. Five scenarios addressing the technical coefficients were investigated while three scenarios were compared for the transaction values.

The changes in input technology are compared in Table 4-5 below. These technical coefficients represent the domestic input technology rather than the technology of the power plant as a whole, hence some input coefficients seem excessive. But since, for example, there is no coal exploitation in southern Thailand that technical coefficient is zero (Department of Mineral Resources, 2016), this does not mean that no coal is needed for the power plants since it is imported, but that there is no domestic input.

Table 4-5: Electricity sector input columns, technical coefficients.

Sector description	BAU	All replaced for new technology	Krabi replaced, 800MW added	Krabi replaced, 1,800MW added	Krabi replaced, 2,800MW added
Natural Gas, LPG	51.09%	0.00%	36.68%	27.12%	21.51%
Petroleum and Natural Gas (Drilling, Exploration)	18.35%	0.00%	13.18%	9.74%	7.73%
Banking Services	11.71%	1.91%	8.94%	7.11%	6.03%
Electricity	7.16%	52.95%	20.07%	28.64%	33.67%
Electrical Machinery	3.69%	8.69%	5.10%	6.04%	6.59%
Restaurants and Hotels	1.44%	1.50%	1.46%	1.47%	1.48%
Industrial Machinery	1.29%	1.18%	1.26%	1.24%	1.22%
Business Service	1.04%	9.92%	3.54%	5.20%	6.18%
Building Construction and Public Works	0.24%	4.59%	1.47%	2.28%	2.76%
Trade, Repair	0.06%	11.44%	3.27%	5.40%	6.65%

Source: Author’s calculations

The first column represents the BAU case. In case that EGAT is not building anything in the region and does not shut down any existing plant, we will have no technological change in the inputs for the power plants in the south. The second column on the other hand represents the opposite, where southern Thailand's electricity producing sector is replaced by Brandenburg's technology with the secondary information on the south's regional economic production. We can see a stark difference in the usage of natural gas and liquefied petroleum gas, and electricity. While in southern Thailand the most domestically produced input into electricity producing entities is natural gas and liquefied petroleum gas, in Brandenburg it is electricity and coal, 29.65% and 9.28% respectively. However, coal is not represented in the table above as there is basically zero domestic coal production in Thailand's south and as mentioned before it is going to be imported entirely, hence we do not see a transformation from natural gas to coal. Also, electricity inputs to the power the power plants increase disproportionately. There are still some natural gas and fuel oil inputs, which includes drilling and exploitation, as Brandenburg still uses some power plants with these primary inputs. The electricity input increase is due to the electricity intensive exhaust cleaning processes for these new clean coal power plants. Other stark changes are in trade and repair, the banking sector, and the business services while the first mentioned sector shows a higher maintenance need of the state-of-the art power plants, the second sector shows a reduction of the banking needs. The business services increase which may be due to the higher use of external services, among others, business services include consultancy services, external research and development, temporary labor employment of specialists and external scientific examinations of the power plant. Furthermore, there are some minor increases in the technological inputs by the building construction and public works sector which mainly represents transmission lines; and in the electrical machinery sector which shows that local businesses could profit by producing electrical machinery for the new clean coal power plants. Surprisingly the industrial machinery sector does not change by much, but rather contracts a bit. This shows that the technology inputs from the industrial machinery sector for the current natural gas power plants are of similar value to the clean coal power plants. Likewise, the input by the tourism sector is basically unaffected by the changes of primary input for the power plants. This does not mean that the change in fuel does not have negative impacts on the region as a tourism spot at all, but rather that the clean coal power plant will need similar restaurant and hotel arrangements as the existing power plants. These travel arrangements are mostly for senior level staff and specialist that need to spend some days or weeks for project related work at the power plants.

The last three columns represent each the replacement of the existing Krabi fuel oil power plant with the construction of one 800MW clean coal power plant, column 3, two clean coal power plants, column 4, and three clean coal power plants in column 4. In column 4 and 5 the additional power plants are both 1,000MW, as the PDP2015 (EPPO, 2015c) proposes. The calculations have been done as follows, the existing stock of power plants, excluding the Krabi fuel oil power plant, have been summed together with the additional clean coal power plants, using Brandenburg's technical coefficients. According to this mathematical procedure, we can see that the more power plants are installed with the technology coefficients of Brandenburg, the higher the similarity of that column to the full technological change.

In Table 4-6 below we can see the additional input needed to operate the three additional units in the south. They are calculated by using the per megawatt-hour (MWh) costs, an 85% capacity and the Schwarze Pumpe power plant's efficiency, excluding fuel and labor. A power plant's costs, or in this case its inputs, are divided up into capital costs, O&M costs, and fuel costs. The labor costs are included in the O&M costs and are about two-thirds of it.

Table 4-6: Electricity sector input columns, transaction values, in USD.

Sector description	800MW Krabi Clean Coal Plant	1,000MW Thepa Unit 1 Clean Coal Plant	1,000MW Thepa Unit 1 Clean Coal Plant
Electricity	23,987,387	53,971,622	83,955,856
Trade, Repair	5,180,721	11,656,622	18,132,523
Business Service	4,492,393	10,107,885	15,723,376
Electrical Machinery	3,938,072	8,860,663	13,783,253
Building Construction and Public Works	2,081,490	4,683,352	7,285,214
Transportation Land	935,057	2,103,878	3,272,699
Real Estate Services	900,328	2,025,738	3,151,147
Banking Services	863,344	1,942,524	3,021,704
Insurance Services	804,401	1,809,902	2,815,403
Restaurants and Hotels	681,135	1,532,555	2,383,974
Industrial Machinery	533,799	1,201,048	1,868,297
Total (including other sectors)	45,302,983	101,931,712	158,560,441

Source: Author's calculations

Now, the sector that profits most is again the electricity sector. The electricity sector needs resources from itself to power the machines that transform the raw coal to a gas or liquid state in order to use the fuel in a more cleaner way. There are other processes, like dewatering, that need power to abate pre-combustion and post-combustion. The other inputs from possible local businesses are quite small at around US dollar (USD)21mio for the Krabi power plant and USD75mio for all three new units together. This shows that the power plant does not consume a lot of intermediate local goods. Coal is sourced from outside the region while operating and maintaining the power plant does not need a lot of local resources. However, one part of the power plant has been neglected, the labor input in the power plant. This constitutes around 10% (Murray, 2009) to the yearly power plant cost. Therefore, these direct labor costs and possible indirect consumption push from staff to the economy may increase the effect of the power plant in a significant way. This needs to be investigated further in future research, possibly with a dynamic general equilibrium model.

Sensitivity analysis

This concludes the regionalization of the two IO tables. Before analyzing the results, the created regional IO tables used to get results underwent a sensitivity analysis according to Wolff (2005). He uses the Leontief matrix to make assumptions on the IO table. The τ value used to compare if the matrices are well-conditioned for a medium-sized matrix is supposed to be around 0.07 – 0.14. I used the statistical program R (R Development Core Team, 2016) to calculate the τ value for all matrices used in this section. We get τ values of between 0.12 – 0.13, hence passing the sensitivity tests.

Table 4-7: τ values for the regional IO tables, dependent on the change in the electricity column.

Electricty column type	Tau
BAU	0.1209
25% replaced	0.1209
50% replaced	0.1208
65% replaced	0.1207
75% replaced	0.1206
Brandenburg technology	0.1203
800MW added	0.1202
1800MW added	0.1208
2800MW added	0.1208

Source: Author’s calculations

4.6 Conclusion

This study has calculated the direct domestic economic impacts of the clean coal power plant in Krabi and the forthcoming units in Songkhla's Thepa district. The power plant certainly increases demand for some sectors, but almost half of the additional demand created by the clean coal power plant is for coal which will be imported. Likewise, the electricity sector itself is the other big benefiter, as the power plant needs electric power to operate. The power plant does give a small boost to the trade and repair, the transport sector, as well as to the business services and electrical machinery sector. The hypothesis that the operation of the clean coal power plant would transform the input coefficients into the electricity producing sector is true for some sectors, gas demand and banking services decreases relatively stark while electricity demand, electrical machinery, business services and trade and repair increase in relative terms. In absolute terms, electricity inputs gain the most, while the trade and repair, the business services, the electrical machinery, and the building construction and public works sectors make some moderate gains as well. Other sectors do not change much in relative and absolute terms. Surprisingly, the industrial machinery sector will only benefit slightly.

The gross provincial product of the cluster of provinces in the south stood at USD36,277mio in 2013. The three clean coal power plant units may induce USD158mio into the economy after they are built, or 0.50% per year. This number excludes the additional salaries paid to the staff of these plants and only includes the direct effects. In a further study, it would be interesting to add the wages and run a dynamic model to estimate the indirect effects as well. The impact on the economy could be substantial when including these indirect effects. Lastly, this section only looks at the benefits of the additional investment in the south while building and operating a fossil fuel power plant would certainly also have costs. Costs are twofold in that the plant would pollute the air and use up land it stands on which are environmental impacts, and there may be social impacts as well. Hence, further research could either construct a cost-benefit analysis of the investment, or different options of primary source for the power plant could be compared. Power plants from renewables are currently getting more cost-efficient and are competing with other power plants in terms of cost, pollution and electricity availability. Furthermore, there is a discussion on how the clean coal power plant impacts the local tourism sector of the western part of southern Thailand, especially with the external effects of pollution. As this study does not cover such an impact analysis, a further study that would study the tourism input column that also includes the adverse effects of pollution would be of interest.

Section 5 – Study 2

5 Clean coal project: carbon certificate pricing

5.1 Abstract

New ultra super-critical coal power plants are proposed to be built in southern Thailand to produce electricity for that area due to its increased electricity demand. In this section, different levelized cost of energy in per MWh for the proposed modern technology clean coal power plant as well as other Thai electricity producing power plants, including renewables and non-renewables, are compared. A hypothetical carbon certificate price per kiloton of CO_2e is estimated that relates the extra cost of the ultra super-critical coal power plant to the cheapest but dirtiest option, a lignite power plant. This shows how much the government subsidizes abatement of air pollution. Furthermore, looking only at subsidizing GHG abatement, levelized cost of energy of renewable power plants are compared to the non-renewables' costs with the hypothetical carbon certificate price. The results show if subsidizing renewables over ultra super-critical coal power plants would be more cost effective and expose the most efficient fuel option to reduce carbon emissions in Thailand. However, no comment can be made which option should be strictly preferred as the electricity price and the environmental costs are only part of the political decision for a country on which primary fuel, or fuel mix, to choose. The study uses secondary data from Thai researchers and international energy organizations on the levelized cost of energy and on the respective power plant's CO_2e emissions from the Intergovernmental Panel on Climate Change (IPCC).

5.2 Introduction

This section analyses the costs and GHG output of modern clean coal power plant technology proposed by EGAT, which is to be used to build power plants in southern Thailand (EGAT, 2013a). The proposed power plants' LCOE and total CO_2e emissions are then related to other possible power plants. This produces two ordered lists of alternatives by their cost of abatement compared to old and modern technology clean coal power plants, similar to the ones built and to be built in Thailand (EGAT, 2017b). These lists also feature renewable power plants. Those power plants however are not fully comparable to a conventional coal power plant, since many of those renewable power plants cannot produce electricity by simply turning them on or store the produced electricity easily and efficiently. Furthermore, the reasons why a coal power plant has been proposed is also assessed, since the decision on what type of and where a power plant is build is a political decision (The Government Public Relations Department, 2017a). The costs are evaluated using the LCOE method that uses the discounted capital costs, fixed and variable O&M costs, and the fuel prices (Murray, 2009). These costs use some variables for the respective power plant's efficiency, an interest rate, the quality of coal and gas, future prices of the respective fuel, and wind quality and solar radiance (Schloemer et al., 2014). On the other side, the total direct CO_2e emissions are taken from the IPCC (Krey et al., 2014). The outcome is a comparison of the costs to produce electric energy and of the amount of CO_2e emissions. Relating the final ranking of the costs of lowering the CO_2e emissions by a ton per year to the EU's ETS price (European Energy Exchange AG, 2017) shows how viable other power plant projects may be.

The proceeding sub-section of this section embodies the literature review, specifies the data sources and states some issues. The fourth sub-section illustrates the LCOE model used and how the implied abatement costs are calculated, while the fifth presents the results. In the last sub-section, conclusions to this section are drawn and possible next steps listed.

5.3 Literature review

The definition of a clean coal power plant can vary a lot and to name a coal power plant clean coal may be a bit misleading as the modern technology plants do not render coal burning clean, but rather less harmful to the environment per electric energy produced. The usual definition is that the power plant has processes in place to reduce the discharge of sulfur and nitrogen pollutants as well as particulate matter to the air (United States Department of Energy, 2013). In the last couple of years, a lot of research has been done to reduce the discharge of GHGs per energy unit produced. A coal power plant that uses these new methods that try to reduce harmful CO_2e output to the atmosphere when burning coal are called clean coal technologies. The power plant proposed by EGAT will produce various kinds of GHG emissions, however, it will feature processes to minimize the exhaust of CO_2, NO_X, SO_2, activated carbon, and various kinds of mercury (EGAT, 2017b). There are different ways to achieve that and EGAT divides them up into three different stages. At the pre-combustion stage, EGAT (2016a) uses higher grade coal that has a high carbon count to simply make the plants more efficient in turning coal to energy. At the combustion stage the power plant uses ultra super-critical pulverized fuel combustion technology, which again means that the process is more efficient in turning coal to electric energy which reduces the discharge of CO_2e per energy unit produced (EGAT, 2015b). Lastly, at the post-combustion stage, four different processes are used to filter out GHG emission, they are selective catalytic reduction, activated carbon injection, electrostatic precipitation, and flue gas desulfurization (Vongmahadlek & Vongmahadlek, 2016). Hence, in the context of this section, the clean coal power plant refers to a high-efficiency, low emission coal power plant without CCS.

Presently, Thailand is in the need of more electricity supply, moreover, the EPPO (2015c) projects that the country will need to almost double the current supply in order to keep up with its demand.

Table 5-1: Total planned capacity changes in Thailand until 2036.

Total capacity in Thailand (incl. imports)	MW
Starting capacity as of December 2014	37,612
Total added capacity 2015 - 2036	57,459
Total retired capacity 2015 - 2036	-24,736
Final capacity as of December 2036	70,335

Source: EPPO (2015c)

In its PDP2015, EGAT lays out how the country and its economy will advance and which fuel sources it projects to use. I will primarily use those for my comparison as well as other modern technology power sources. EGAT projects the future power demand from the future composition of the economy, its growth rate and subtracts advances in energy savings in the years 2015-2036. Power sources considered are coal, gas, nuclear and renewable power plants as the government wants to diversify its fuel mix.

There are various international bodies that periodically estimate and publish LCOE of power plants such as the International Energy Agency (2017), the IPCC (2017) and the International Renewable Energy Agency (IRENA) (2017). Furthermore, Wangjiraniran et al. (2013) and Pattanapongchai and Limmeechokchai (2011) estimated costs for different Thai power plants. The LCOE is the price of energy where costs equal revenues, including a profit on the capital invested. The secondary data on the cost of power plants' electricity production are more recent from these international bodies since they update their parameters whenever they make a new assessment. Considering the fast-paced changes in the technology used and costs for renewable power plants, it is important to get the latest numbers on the latest cutting edge power plants. By 2025, levelized costs for onshore and offshore wind may decrease by 26% and 35%, respectively; for solar photovoltaic (PV) and concentrating solar power (CSP) the price decrease may be around 59% and 43% compared to 2015 (IRENA, 2016b). Regarding the data on costs for the old clean coal technology power plant, the first mentioned paper by Wangjiraniran et al. (2013) assesses the overall costs of energy of old power plant technology. Thus, I use their cost structure to calculate old clean coal technology LCOE, using the same method as for the other coal power plant's LCOE (Schloemer et al., 2014). Wangjiraniran et al. compare different fuel mix scenarios and conclude that the mix of power generation can significantly affect the cost of electricity as well as GHG emissions, hence the policy maker needs to take both measures into account when developing a power development plan. The other paper by Pattanapongchai and Limmeechokchai (2011) touches on the same topic and uses similar data, but focuses on CCS to compare its cost effectiveness related to cost. They conclude that CCS may play an important role in CO_2 mitigation. In this study, we are looking at the new power plant that may be built in Thailand, hence we are concerned about the latest technology for each respective fuel source, which means I will draw the cost data from the most recent source. Thus, data from IRENA is used for all renewable energy sources. The intergovernmental organization recently produced a report on wind and solar power plants' LCOE (IRENA, 2016b). For the other power plants, the IPCC released a report covering LCOE and emission quantities of gas, coal and nuclear technology power plants (IPCC, 2014). Therefore, this study will use their secondary data to compare it with the renewables' LCOE as well as to the current Thai clean coal power plant's levelized costs and GHG emissions.

The GHG emission for each power plant are estimated by the IPCC (Krey et al., 2014). Their study includes figures on both, direct emissions and the lifecycle assessment (LCA). Both methods are calculated to represent a weight of CO_2e per MWh which includes various GHGs (Krey et al., 2014) in a common unit. The direct emissions are emissions that coal and gas power plants emit by using fossil fuels. Lifecycle emissions include direct emissions and indirect emissions. The indirect emissions stem from three parts. First, infrastructure and supply chain emissions which include the construction and decommissioning of power plants. Solar PV has a large polluting effect in the decommissioning part, hence, its emissions increase from 0 to 48 CO_2e per MWh, while other renewables are only increasing to about half this value in the LCA. Second, there are biogenic CO_2 emissions and albedo effect. These effects are mainly from biomass and, solar and hydroelectric dams. The albedo effect is solar radiation that is reflected from earth's surface back into space (Earth & Space

Research, 2017). Lastly, methane emissions from mining coal and gas as well as rotting vegetation from hydroelectric dams yet again. For this study, only the direct emissions by the different GHGs are considered. The LCA method may be preferred when emphasizing total CO_2e emissions, however, we estimate a hypothetical carbon emission price without the indirect emissions from the supply chain, especially since coal and gas would be imported. Yet, for biomass we use the LCA results instead of direct emissions. According to IPCC (2017) this is to reduce double counting of emissions and removals. To keep the text simple, henceforth, I use the wording direct emissions for biomass as well.

Thailand's PDP2015 (EPPO, 2015c) outlines the future power system development framework for the country. The plan presents which technologies the policy planers are supporting. The technologies include power plants using coal, gas and uranium as fuel as well as various renewable energy plants. Accordingly, clean coal power plants with pulverized coal, CC gas power plants as well as nuclear power plants are included in this study. Regarding renewable power plants, the Alternative Energy Development Plan (EPPO, 2015a) lists which type of sustainable energy that are going to be constructed in Thailand. To limit the different types of renewable power plants, technology types that have a target of above 1,000MW by 2036 are included, these are biomass, wind and solar. Wind and solar includes onshore and offshore for wind, and utility-scale crystalline-silicon PV and parabolic and tower CSP plants for solar respectively. Hydro power plants are not included as no significant new additions can potentially be added to the grid at a reasonable price. Furthermore, I will also include the costs and emissions of IGCC power plants, since this is the technology frontier for coal along with the CCS process for all the conventional coal and gas power plants.

In the next couple of paragraphs, the characteristics of the power plants are described. Each primary fuel source characteristic, depending on its fuel type, its technology used, or the wind quality and solar radiance, can have profoundly different costs or GHGs emissions. Excluding the old technology coal power plant, the other coal and gas technology plants use coal and natural gas types that is bituminous coal (Department of Mineral Resources, 2013) with an assumed lower heating value of 26,151 kJ/kg, and 47,454 kJ/kg for natural gas respectively (United States Department of Energy, 2015a). This is the same type of coal (EGAT, 2015a) that is going to be imported for the new clean coal power plants in Thailand from Indonesia (Argus Media Group, 2017).

The coal data, except for the old technology clean coal power plant and the IGCC technology without CCS, is taken from IPCC (2014). Their report features data on all variables to calculate the LCOE, with overnight capital expenditure costs, fixed and variable costs, and fuel costs, as well as the plant's efficiency and capacity utilization or full load hours. Additionally, the construction duration and the plant life are assumed as in a report by the International Energy Agency and the OECD Nuclear Energy Agency (2015).

There are different parameters that define a scenario of possible electricity costs per power plant technology and each of these scenarios in turn have minimum, median and maximum values. If not mentioned otherwise I am using median values for the direct emissions and LCOE. The report defines the four scenarios as follows, (i) a 10% weighted average cost of capital (WACC), high capacity utilization and no carbon emission costs, (ii) a change in WACC to 5% compared to (i), (iii) a change in the capacity utilization to low compared to (i), and (iv) adding a carbon price of USD108.67 per ton of direct CO_2e emissions versus scenario (i). Similarly to scenario (i), IRENA (2016c) uses a weighted average capital cost of 10% for countries not in the OECD, hence for comparability reasons we do not take scenario (ii). The low capacity scenario can also be ruled out for our study, since Thailand's south, where the clean coal power plants are to be built produces too little electric energy (EGAT, 2016b), along with Thailand's 4-5% electricity demand increases per year (International Energy Agency, 2016). Ergo, we assume that the power plant is running at high capacity. Lastly, we are calculating a theoretical carbon price, hence scenario four is also neglected. Accordingly, this study uses scenario (i).

IGCC coal technology is at the technology frontier. It gasifies coal and then generates electricity with a CC gas turbine (Siemens, 2017). The median LCOE for this type of coal power plant is calculated using overnight as well as fixed and variable O&M costs data from the United States Energy Information Administration (2013). For comparability reasons, the other parameters such as the discount rate, the capacity utilization, the plant's life span, and fuel costs are taken from the IPCC report. The same, except for fuel cost and the plant's lifetime, goes for old technology coal power plants, with a lifetime of 33 years (EGAT, 2013b). For all other, modern technology, coal power plants, we are using a lifetime of 40 years. The cost data are taken from a paper by Wangjiraniran et al. (2013). The power plant uses lignite which is a low-quality coal type that is mined next to the power plant (EGAT, 2016d). Furthermore, the power plant's efficiency is subcritical at 35% (Wangjiraniran & Euaarporn, 2010) and features flue-gas desulfurization. Regarding CCS, the additional process includes the transport and storage costs at USD10.87 per ton of CO_2 and an assumed sequestration level of 90% for the supercritical pulverized coal power plant (Hertwich et al., 2014) and the IGCC power plant technology (Corsten, Ramirez, Shen, Koornneef, & Faaij, 2013).

There are no fuel or other technical constraints in deploying the modern clean coal technologies in Thailand. However, the government prefers a location near to the sea, since the bituminous coal is imported from abroad by ship, this would keep transportation costs low. Yet, there are local objections to some of the new clean coal power plants. To assure the public of minimal environmental burdens, the government is reviewing the environmental impact and environmental health impact assessments (The Government Public Relations Department, 2017b). Hence, we assume that EGAT could build the clean coal technology in Thailand at the LCOE value proposed in the IPCC report. Another important factor concerning the fuel choice of a power plant is the future price of that fuel and its availability. The future price and the availability of the fuel are somewhat interlinked. The more reserves and resources are available, the lower the future price increases. The Federal Institute for Geosciences and Natural Resources (2013) forecasts that coal will continue to play a significant role as an energy supplier and that there are adequate reserves and resources for many decades to come, which is similar for natural gas. Hence, we assume the mid-level costs of the IPCC report for this study of USD4.46 per gigajoule for bituminous coal, and USD9.67 for natural gas respectively.

Similar assumptions are considered for CC gas power plants with and without CCS. Relative to coal technology plants, they are built in 4 years, instead of 5, but last only for 30 years (International Energy Agency, 2010). At the time of the IPCC study there was no commercially run CC gas power plant with CCS (Black & Veatch, 2012), hence, the values are calculated by adding empirical coal CCS values to a CC gas power plant with a reduced plant efficiency (Rubin & Zhai, 2012). A sequestration level of 90% is used in the case of the gas power plant as well (Singh, Stromman, & Hertwich, 2011).

The cost and specifications data on nuclear power plants are limited because of minimal recent data (Schloemer et al., 2014). Lenzen (2008) provides an exhaustive review of nuclear power plants, however, the latest plant reviewed was built in 2004. Moreover, Thailand's PDP2015 (EPPO, 2015c) marks the construction of the nuclear power plant for 2035, thus, the technology in 2035 may not be comparable to what was deployed in 2004 Since there is no other comparable data available, we use IPCC's values.

The renewable power plants may not be able to be built in the locations where the ultra super-critical clean coal power plants are proposed, since these sites may not have ideal wind quality or solar radiance, or may not be able to supply enough biomass regionally (IRENA, 2015a). In Thailand, biomass is manly used in heat production, at about 64% in 2014 (EPPO, 2015a). However, EGAT has an electricity generation target of biomass of around 5.6gigawatt (GW) in 2036 from 2.5GW in 2014, with the fuel mainly being agricultural residues (Peerapong & Limmeechokchai, 2016). Thus, the type of power plant considered in this study is a 20MW low-cost stoker boiler using agricultural residues (Department of Alternative Energy Development and Efficiency, 2012) that has costs of USD50/ton, with cost data from IRENA (2012a).

Nowadays, there are many different solar power plant technology, yet only three are considered for the comparison, first-generation utility-scale crystalline-silicone PV without energy storage, parabolic CSP, and tower CSP. The first type is the most widespread solar technology in the world (IRENA, 2016a). Yet, the installations are very small in power generating capacity, around 30% of solar PV capacity are systems of less than 100kilowatt (kW). IRENA (2016b) uses utility-scale solar power of more than 1MW with a capacity factor of 18%. Solar PV are not reliant on direct solar irradiance as strongly as the CSP technologies, because they can also use diffuse solar irradiation (IRENA, 2012c). This makes the technology available everywhere in the world. In Thailand, the total solar radiation is around 1,700-1,900 kWh/m2, while only 52% of this is direct radiation because of the tropical climate and low latitude (Janjai, Masiri, Pattarapanitchai, & Laksanaboonsong, 2013). For a specific site in Thailand, in Chon Buri, two distinct seasons with a low irradiance during monsoon from June to October and high irradiance between November and May could be measured (Krueger, Rakwichian, Sukchai, & Pongtornkulpanich, 2012). The high irradiance periods coincidence with peak electricity demand by month (EPPO, 2017) driven by cooling in the hot season as well as by the time of the day. The global weighted average LCOE for solar PV is taken for this study, it coincides with the Asian weighted average which is also similar to the European and North American weighted averages (IRENA, 2016b). The nameplate efficiency of solar PV decreases over time. It depends on the weather conditions at its location. Yet, utility-scale crystalline-silicone PV can have a nameplate of over 25% efficiency in 2015, according to Green, Emery, Hishikawa, Warta, and Dunlop (2015). Accordingly, assuming a lifetime efficiency of 18% is not restrict this study.

CSP plants use mirrors to concentrate solar heat onto a fluid to produce power generating steam, using steam turbines to then generate electric energy. This process can store some of the solar rays as heat and continue to produce electricity when there is no solar light. Parabolic CSP is the dominant technology over tower CSP. Parabolic trough collectors concentrate the sun’s rays along tubes filled with a heat transfer fluid. While the analysis uses thermal storage of 7.5 hours, the current systems can store up to more than 18 hours. The optimal power plant design is a balance of the parameters of thermal storage, capacity factor and the solar multiple. The parabolic reference plant that we are using is from IRENA (2016b), a site of direct solar irradiance of 2,000 kWh/m2 per year, with a 160MW output and a capacity factor or 41%, with a solar multiple of around 2 (IRENA, 2012b). The parameters for the tower CSP are similar with a smaller plant at 150MW, a higher capacity factor at 46% and a longer thermal storage time of 9 hours. The solar tower power plant differentiates from the parabolic though one in that the concentrated sun rays are collected on mirrors that are then focused onto a receiver mounted on a tower.

Lastly, wind power plants are included in the study as well. Most modern wind power plants are horizontal axis wind turbines. There are two plant types based on location, wind turbines on land and offshore. For this section, we analyze wind turbine hub heights of between 80m to 120m (IRENA, 2016b) and diameters of around 90m to 100m. The cut-in wind speed for these types of power plants is as low as 3m/s, while the cut-out speed, where the turbine shuts down to avoid damage, is at 25m/s. Incidentally, Manomaiphiboon et al. (2017) use these parameters for their study on the wind power potential at wind speeds of 3-5m/s (Quan & Leephakpreeda, 2015). They conclude that using a low-speed turbine technology, Thailand could build wind power plants totaling 17GW, yet only 5GW with conventional wind power plants. For the calculation of the LCOE of onshore wind power plants, only plants with a system design of above 5MW are included, also no energy storage is considered for both, onshore and offshore plants. However, for wind power farms offshore, the LCOE is calculated using farms of a capacity larger than 200MW. Both types also use different capacity factors, 27% for onshore wind and 45% for offshore wind since the higher wind speeds and more availability raise the capacity factor (IRENA, 2016d). Offshore wind power, as well as the CSP are still in their infancy. Cost savings over the next couple of years can be anticipated, but the LCOE of offshore wind are still relatively high compared to its onshore counterpart, mainly because of its construction and foundation offshore (IRENA, 2012d). In this study, the average water depth is 20-30m with the wind power plant using a monopile foundation (IRENA, 2016d).

The LCOE for renewable power plants are from recent reports by IRENA (2016b) & IRENA (2012a). Subsidies, taxes, and insurance costs are not considered for the power plants' LCOE. Costs for infrastructure other than the power plant itself are not included in the LCOE. This includes grid connections as well as the conveyer belt and tunnel that EGAT (2016a) is building to connect the coal shipments to the Krabi clean coal power plant. Unlike conventional power plants using coal, gas, and uranium; most renewable power plants have no fuel costs and relatively low O&M costs. Consequently, capital and installation costs, are major cost drivers. The capital costs also include financing costs. Changing the WACC from 10% to 0% for wind and solar power plants can lead to a more than 50% reduction in their LCOE. Likewise, the amount of solar irradiation and the wind quality influence a project's viability to a point that these power plants cannot be built just at any location. Hence, higher LCOE in some countries do not necessarily mean inefficient capital cost structures.

To relate the abatement cost of other power plants, we also need the direct emissions, and a carbon certificate price as a reference point. The direct emissions are denoted in kg CO_2e per MWh. The various GHGs are converted from their emission weight to a CO_2e (IPCC, 2007). The renewable power plants do not have any direct emissions, while coal, gas and biomass do. The carbon certificate price used as a reference point is taken from the European Energy Exchange AG (2017) that operates the CO_2 certificate market in Europe, which is called the EU ETS. It is liquid and therefore, we have a good approximation of real world market prices. In a report for energy, transport and GHG emissions trends (European Commission, 2013), the European Commission forecasts the price up to 2050. Accordingly, a discounted carbon certificate price is estimated for 35 years, starting from 2015. That price is assumed to reflect the lifetime of gas and coal power plant which have a lifetime of 30 years and 40 years, respectively. The GHG emissions valued at the EU ETS market price are the only external costs associated with the power plants. I am not including them in the LCOE calculations, but rather compare these external costs to the results, which is the price of mitigation of a ton of CO_2. Furthermore, the externality could also be calculated as the social cost of carbon. The social cost estimations vary a lot from USD72.97-291.90 (Clarkson & Kathryn, 2002) to USD978.04 (Ackerman & Stanton, 2012), hence we use actual market prices.

I will relate the, usual, higher costs of cleaner power plants versus the clean coal power plants over the amount of their CO_2e abatement according to the paper of Sims et al. (2003). More recently, Lazard (2016), a preeminent financial advisory firm, uses the same method in their yearly LCOE analysis. However, carbon fuel and nuclear power plants are not truly comparable to renewable power plants without any assumptions. A small PV power plant may only produce electricity during certain times of the day. On certain times the PV system may produce excess electricity and without storage or distribution on the grid, this may lead to curtailments and an efficiency decrease of the renewable power plants (United States Department of Energy, 2015b). Storing electricity or thermal energy however, makes the power plant's construction cost more expensive, but in the case of thermal energy storage with CSPs, the LCOE may go down because the plant's large capacity factor increases. Hence, renewable power plants without the right amount of storage or a good grid connectivity and management cannot be compared to conventional coal, gas and nuclear power plants. Thus, a decoupling of electric energy demand and supply is necessary (Carrasco et al., 2006), this in turn renders these plants comparable on an LCOE basis. Ergo, we assume the grid will be able to handle less centralized electricity production (Battaglini, Lilliestam, Haas, & Patt, 2009). This is especially true for the low level of renewables Thailand currently has connected to the grid. The deployment of more renewable energy systems leads to a decentralized electricity production which in turn may also reduce transmission line losses and costs (Masters, 2004). Other advantages of most renewable power plants over other power plants in that they do not depend on the future fuel prices or fuel availability, hence they could be used to hedge against volatile fossil fuel prices. However, this can be pitted against their reliability issues in production.

5.4 Model

Sims et al. (2003) compared emissions to costs of a modern technology power plants and assessed a price of mitigation per ton of carbon emissions avoided. This study uses the same method. First, the LCOE and direct emissions per each power plant must be estimated, then the results of each pair are divided to obtain the avoided carbon mitigation costs.

The LCOE for coal, gas and nuclear power plants are described in the IPCC Fifth Assessment report (Schloemer et al., 2014) and are denoted in USD/MWh, with constant 2015 US dollar for all dollar values in this thesis. Below is the formula for LCOE; the parameters for the formula are in Table 5-2.

$$LCOE = \frac{\alpha * I + OM + F}{E}$$

Table 5-2: Parameters for the levelized cost of energy formula.

Parameters	Description
$\alpha = \frac{r}{1-(1+r)^{-L_T}}$	α is the capital recovery factor. r is the WACC, $r = 0.1$. L_T is the projected duration (in operation).
$I = \frac{C}{L_B}\sum_{t=1}^{L_B}(1+i)^t$	I is the investment cost, including finance costs. C is the capital costs, excluding finance costs for construction, also called the overnight capital expenditure. L_B is the construction duration. i is the interest rate over the construction loan, $i = 0.05$.
$OM = FOM + (VOM + d) * E$	OM are the net annual O&M costs. FOM are the annual fixed O&M costs. VOM are the annual variable O&M costs. d is the decommissioning cost, $d = 0$ $\forall$ power plant, but $d = 0.15$ for nuclear power. E is the electric energy produced annually, see below.
$E = P * FLH$	E is the electric energy produced annually. P is the capacity of the power plant, $P = 1MW$. FLH are the number of full load hours, or capacity utilization.
$F = FC * \frac{E}{\eta}$	F are the annual fuel costs. FC are the annual fuel costs per unit of energy input. η is the conversion efficiency (in lower heating value), or the plant's efficiency.

Source: Schloemer et al. (2014)

Thus, according to the formula above the LCOE are the summed costs of the discounted lifetime investment, O&M, and fuel divided by the lifetime output of the power plant (IRENA, 2015b). The construction duration does not include any planning or political process prior to groundbreaking. The existing and the IGCC coal power plant were calculated this way with data from Wangjiraniran et al. (2013) and EGAT (2013b) for the existing, and the United States Energy Information Administration (2013) for the IGCC respectively. As stated before, some parameters such as the WACC, the full load hours, and no carbon costs are assumed from the IPCC report to be able to compare the calculated LCOE of those two plants to the others under scenario (i).

The International Energy Agency as well as most countries in the world attach energy use and CO_2e emissions directly to the energy producing sector for calculation purposes. Albeit electricity and heating or cooling consumption of the end user is the actual user of energy and emitter of GHGs. The direct emissions are the emissions produced upstream starting at the power plant. Consequently, mining for coal and gas, or the production of PV systems are neglected. The direct emissions per MWh depend on the characteristics of the power plant, especially on the efficiency of turning carbon to electricity and on the fuel quality. The fuel quality is described in the literature review and median efficiency is assumed for the average direct emissions. Furthermore, as already mentioned, each GHG is converted to a CO_2e with the global warming potential (United States Environmental Protection Agency, 2015). The data is from IPCC for all gas and coal power plants except for the old technology Thai coal power plant which has been estimated by EGAT (Wongsarat, 2016). The renewables and the nuclear power plant do not have any direct emissions in this study.

The mitigation costs of carbon emissions avoided are calculated with the formula below; while its parameters are described in Table 5-3.

$$implied\ abatement\ costs = \frac{(LCOE_i - LCOE_j)}{abs(CO2e_i - CO2e_j)}$$

Table 5-3: Implied abatement costs.

Parameters	Description
i, j	i is a power plant technology different from j. j is the base power plant technology.
$LCOE_{i,j}$	$LCOE_{i,j}$ are the levelized cost of energy of technology i or j.
$CO2e_{i,j}$	$CO2e_{i,j}$ are the direct CO_2e emissions of technology i or j.

Source: Sims, Rogner, and Gregory (2003)

The implied abatement costs formula calculates the price in USD of mitigation per ton of CO_2e avoided. Before calculations, we select special cases out where both, the costs and the GHG emissions per MWh are lower relative to the base technology. This means that this technology is strictly superior to the base technology. For the remaining technologies, the mitigation formula produces positive results, that is costs, when the LCOE for the base technology is cheaper than the alternative technology. Contrarily, when the result is negative, we save money, but pollute more.

The power plant technologies mentioned in the literature review are compared to the old and new technology clean coal power plants. The results show the most efficient technologies, relating to GHG emission abatement, in replacing those two coal power plant types.

These costs are then also related to the discounted carbon certificate price of the EU ETS. Assuming Thailand would adopt that price, we can then divide the technologies into two distinct groups, the group that would be cheaper than the base technology and the group that would be more expensive; cheaper here means more efficiently abating GHG emissions.

5.5 Results

Intermediate results

The results are divided up into three parts. First, a discussion on the technical characteristics and the cost of the studied power plant technologies and a comparison of the LCOE and the direct emissions are presented. Then, we analyze the results which are the implied abatement costs of the power plant technologies to the existing and new clean coal power plant in Thailand. Lastly, a sensitivity analysis is done to confirm the research outcome.

The table below lists the power plants studied with their lifetime, construction duration, efficiency and capacity factor. The construction duration for PVs are instant, hence, I did not add a value. Also, there are no efficiencies for the solar and wind power technologies, since this is already included in their power output. The capacity factor illustrates how many hours the power plant is producing energy per time unit. For PV technology this means that a 1kW PV unit can produce 4.32kWh of electric energy per day, 1,576kWh per year respectively.

Table 5-4: Technical characteristics of the studied power plant technologies.

Technology	Lifetime years	Construction duration years	Efficiency %	Capacity factor %
New clean coal	40	5	43%	84%
Old clean coal	33	5	35%	84%
IGCC coal	40	5	44%	84%
New clean coal CCS	40	5	30%	84%
IGCC coal CCS	40	5	32%	84%
Combined-cycle gas	30	4	55%	84%
Combined-cycle gas CCS	30	4	47%	84%
Nuclear	40	9	33%	84%
Biomass	40	4	35%	84%
Photovoltaic	25	-	-	18%
Parabolic CSP	20	2	-	41%
Tower CSP	20	2	-	46%
Onshore wind	25	1	-	27%
Offshore wind	25	3	-	45%

Source: Schloemer et al. (2014), IRENA (2016b), United States Energy Information Administration (2013), IRENA (2012a), Wangjiraniran, Nidhiritdhikrai, and Euaarporn (2013), EGAT (2013b)

The cost assumptions are mainly from the Fifth Assessment Report of the IPCC and IRENA (2016b). Missing cost data has been combined with cost data from other sources. The overnight capital expenditure are the capital costs, while the O&M costs are separated into a fixed and variable part, lastly fuel prices are assumed. Solar and wind power technologies do not have fuel costs and are only featured as in fixed or variable costs. PV’s O&M costs are usually only given as fixed, since its cost does not depend on production. The other solar and wind power do have fixed and variable costs in some sources, however, this section uses IRENA’s assumptions. The assumption of a 10% WACC, or discount rate, influences the value of the LCOE for renewables considerably, since there are no fuel costs but rather high installation costs. Hence, over time, with certain renewable power technologies maturing in Thailand, there will be lower WACC and therefore also significant lower costs on installing these technologies. Thus, it is important to see this study as a summation of the current situation.

Table 5-5: Cost of the studied power plant technologies.

Technology	Overnight capital expenditure USD/kW	Fixed annual O&M costs USD/kW	Variable annual O&M costs USD/MWh	Average fuel price USD/GJ
New clean coal	2,391	25.0	3.7	4.5
Old clean coal	1,521	10.5	6.2	3.2
IGCC coal	4,224	58.6	7.4	4.5
Clean coal CCS	4,021	48.9	16.3	4.5
IGCC coal CCS	4,021	25.0	14.1	4.5
Combined-cycle gas	1,195	7.6	3.5	9.7
Combined-cycle gas CCS	1,627	14.1	9.0	9.7
Nuclear	4,673	0.0	14.1	0.9
Biomass	2,608	52.2	5.4	5.0
Photovoltaic	1,800	10.0	-	-
Parabolic CSP	4,900	-	20.0	-
Tower CSP	4,900	-	30.0	-
Onshore wind	1,325	-	10.0	-
Offshore wind	4,400	141.0	-	-

Source: Schloemer et al. (2014), IRENA (2016b), United States Energy Information Administration (2013), IRENA (2012a), Wangjiraniran et al. (2013), Rubin and Zhai (2012)

The cost data and direct CO_2e emissions are presented in Table 5-6 below. The table represents a simple ranking of the technologies with respect to their LCOE from lowest to highest. The costs of electricity and the weight of their emissions in production are shown per MWh, and as already mentioned, the emissions are counted upstream from electricity production from the power plant, hence the nuclear and most of the renewable power plants have zero direct emissions.

Table 5-6: Levelized cost of electric energy and direct emission with their respective rank.

Technology	LCOE USD/MWh	Rank LCOE	Direct emissions kgCO2e/MWh	Rank Direct emissions
Old clean coal	63.0	1	1036	14
Onshore wind	71.0	2	0	1
New clean coal	84.8	3	760	13
Combined-cycle gas	85.9	4	370	11
Nuclear	99.0	5	0	1
Biomass	108.7	6	230	10
Combined-cycle gas CCS	108.7	6	57	7
IGCC coal	117.7	8	734	12
Photovoltaic	130.0	9	0	1
IGCC coal CCS	130.4	10	120	8
New clean coal CCS	141.3	11	120	8
Offshore wind	170.0	12	0	1
Tower CSP	185.0	13	0	1
Parabolic CSP	190.0	14	0	1

Source: IPCC (2014), IRENA (2012a) & IRENA (2016b), and author's

The coal power plant with old technology produces energy at the lowest costs, but at the same time emits the most GHGs in terms of CO_2e. Surprisingly, a renewable energy source is at second place. Modern technology onshore wind power may be cheaper than new high efficient coal or gas power plants. However, the costs depend on favorable wind conditions which means that these power plants cannot be constructed everywhere and may not be able produce enough nor reliable energy for Thailand. Then we have the modern clean coal and the CC gas power plants with similar prices, but with the gas plant emitting less than half the global warming potential of the clean coal technology. Nuclear comes fifth in energy costs and has zero emissions in CO_2e. Utility-scale crystalline-silicone PV power plants have attracted attention in the last couple of years as its costs decreased dramatically (IRENA, 2016b). However, its costs are still relatively high. Hence, PV technology still needs to be incentivized with subsidies like FiT, over cheaper energy sources like coal and gas. CCS technologies are not yet mature, but rather a revolutionary technology according to the United States Energy Information Administration (2016), hence these costs are still quite high as well. Offshore wind and CSP power plants complete the list. These renewable power plants are quite expensive though. Offshore wind is relatively more expensive compared to its onshore counterpart mainly due to the higher construction costs and the more expensive foundation. CSPs have not been widely deployed, learning effects will reduce these costs substantially over the next ten years.

Results

Now, given these costs and emissions, we can calculate a price for CO_2e emissions that would make the base power plant equally expensive to the other technologies, respectively EGAT indifferent based on costs. As stated before, the base technology is an arbitrary starting point. The next table shows the implied abatement cost using the dirties technology as the base. The implied costs can be read as the tonnage price of CO_2e in order to make the modern power plant technology economically as efficient as the old clean coal power plant. This ranking, in Table 5-7, may be used to debate which modern technology best replaces old technology coal power plants; while Table 5-8 presents the results for the debate on more efficient options for GHG abatement compared with the modern technology clean coal power plants that are going to be built in southern Thailand.

When comparing the efficiency in abating GHGs relatively to the old technology coal power plant we can see that the ranking is similar to Table 5-6. Modern clean coal and IGCC coal are being pushed back a couple of ranks though. The modern clean coal technology is reducing emissions compared to the old power plant technology by about 25%, but in a relatively less cost-efficient manner than other power plants. This is even worse for the IGCC power plant which is taking the last place.

Table 5-7: Implied abatement costs compared to an old technology coal power plant.

Technology	Implied abatement costs USD/tonCO2e	Rank Abatement costs
Old clean coal	Base	Base
Onshore wind	8	1
Combined-cycle gas	34	2
Nuclear	35	3
Combined-cycle gas CCS	47	4
Biomass	57	5
Photovoltaic	65	6
IGCC coal CCS	74	7
New clean coal	79	8
New clean coal CCS	85	9
Offshore wind	103	10
Tower CSP	118	11
Parabolic CSP	123	12
IGCC coal	181	13
ETS price USD/tonCO2	10.99	Discounted over the next 35 years

Source: Author's calculations

This means that power plants with very low or zero emissions are relatively more efficient abating CO_2e when comparing to old technology power plants with high emissions. Onshore wind is taking a top spot due to its cheap LCOE and zero emissions. It is the only power plant that would have lower LCOE than the base plant if air pollution externalities at the discounted EU ETS carbon price are taken in account. In order for other renewable power plants to have the same costs per MWh as the old clean coal technology power plant, a carbon certificate price of USD57 and USD65 needs to be prevalent for biomass and PV, respectively. The technologies that are not yet mature such as the CCS, IGCC, offshore wind, and CSPs would need a high carbon price in order for them to be able to compete against the coal power plant with old technology. As in the previous table, gas' carbon costs are relatively cheap, it is also an interesting option for a coal-to-gas switch to reduce CO_2e emissions. The International Energy Agency (2013) estimates a long-term carbon price of about

USD36 for a coal-to-gas investment switch, which coincides with our estimate of USD34. However, in the case of Thailand we are actually looking at a politically induced gas-to-coal switch, since the government wants to reduce its dependency on gas and keep energy costs low with a stable and secure electricity supply.

Thus, in Table 5-8 below we compare the clean coal technology EGAT wants to build in southern Thailand with other emission reducing power plant options. Comparing the modern clean coal power plant to the old clean coal power plant, we detect the only value that is negative which means that the carbon costs are below zero. Hence, EGAT is subsidizing the clean coal power plant to reduce CO_2e emissions versus the old technology coal power plant by building a more expensive, modern technology coal power plant with lower emission. The other power plants except for onshore wind do have positive carbon costs if we want to reduce the GHG emissions further from the modern technology coal power plant base. Also, all other power plant technologies, except for the mentioned old coal technology, would be cleaner than the proposed clean coal power plant, yet also more expensive, except for the onshore wind power plant.

Table 5-8: Implied abatement costs compared to a clean coal power plant.

Technology	Implied abatement costs USD/tCO2e	Rank Abatement costs
New clean coal	Base	Base
Onshore wind	cheaper and less CO2	1
Old clean coal	-79	2
Combined-cycle gas	3	3
Nuclear	19	4
Combined-cycle gas CCS	34	5
Biomass	45	6
Photovoltaic	60	7
IGCC coal CCS	71	8
New clean coal CCS	88	9
Offshore wind	112	10
Tower CSP	132	11
Parabolic CSP	138	12
IGCC coal	1266	13
ETS price USD/tonCO2	10.99	Discounted over the next 35 years

Source: Author's calculations

Consequently, we can say that onshore wind would be able to replace the clean coal power plant based on cost while also emitting zero GHG. However, as mentioned before, renewable energy has some characteristics that conventional coal, gas or nuclear power plants do not have. There are two major problems (EGAT, 2017a), first, energy availability and second the primary energy source quality, in the case of wind power, wind resource quality. Regarding the first issue, coal power plants for example can be turned on at will as long as there is coal while a wind power plant may not deliver energy on a constant basis throughout the day, week or year. Hence, when the Thai government states (The Government Public Relations Department, 2017a) that it would like to have a stable energy supply it points towards this drawback in renewable power plants. A stable supply of energy with renewable power plants can only be achieved when excess energy, if any, is stored in potential, thermal, residential and other storage types (Masters, 2004). Electric energy storage would add costs to the LCOE through higher capital costs, but it would also increase the efficiency of some renewable power plants which has the opposite price effect. IRENA (2012c) estimated the costs of PV against PVs with batteries and concluded that the capital cost effect is currently larger than the savings effect through efficiency. For comparison, a utility-scale crystalline-silicon PV system without battery had lower end LCOE of USD260 per MWh, while with batteries the lower LCOE was USD370 per MWh in 2011. The quality of the energy source is the second issue. Wind is not available everywhere, hence the wind power plant should only be built where the wind quality is good enough to get a decent efficiency. Very low and overly high wind speeds, or no wind at all result in a lower efficiency which reduces the electricity energy produced and can increase LCOE substantially. Accordingly, the potential of onshore wind at the given LCOE is around 5GW. The PDP2015 already projects to build 3GW of wind power by 2036, hence there is a potential increase of 2GW possible, not enough to replace all planned coal power plants at 7.39GW (EPPO, 2015c). Especially when we compare energy rather than power, with onshore wind power’s capacity factor at 27% versus coal power’s at 84%. The actual wind potential, including more expensive onshore wind power plants, is higher at around 17GW. This availability problem is similar for solar energy as well.

The lowest positive carbon costs per ton of CO_2e exhibits the CC gas technology. We also observe a lower carbon price relative to the EU ETS, therefore, when including these carbon costs as a part of the LCOE, gas would be cheaper than the clean coal power plant. Nonetheless, this technology is not a viable alternative since the government’s policy is to reduce its dependency on natural gas by building clean coal power plants. The emission rights prices for nuclear power plants are low as well, but the government’s PDP2015 projects to build two units in 2035 and 2036. Ergo, their construction is uncertain, especially the technology that will be used.

CC gas power plants with CCS and biomass do have similar emission costs. The former is not an option for the same reason as the CC power plant above, while the latter is promoted in Thailand. The exact LCOE, however, depends strongly on the technology, the biomass used to produce electric energy, and the availability of that primary energy source. A study by Thailand’s Department of Alternative Energy Development and Efficiency (Achawangkul, 2015b) shows the remaining power potential for biomass at 6.04GW, with 5.57GW already included to be built in the PDP2015, hence this technology is also not a applicable to replace the planned clean coal power plants.

PV power plants are still relatively expensive compared to clean coal. The technology experiences zero emissions, but its LCOE are still more than 50% higher than modern clean coal power. Furthermore, it faces the same concerns as wind power does in its energy availability and solar quality. However, the power potential is large, estimated at over 40GW (Achawangkul, 2015a). At 2023 if costs keep decreasing, IRENA (2016b) forecasts that solar PV's LCOE may decrease by around 60% relative to its 2015 costs, this electricity energy source may be an alternative soon. A benefit of this, and wind's, technology is that it is not dependent on the future fuel or carbon price. A significant increase of the coal price compared to the base case included in the LCOE calculations is, however, not very likely due to the abundance of coal (BGR, 2013). The carbon price, contrarily, is a rather political decision. Shifting policies of governments regulating the upper limit of CO_2e emissions may suddenly increase carbon costs. Thence, if Thailand would introduce a carbon certificate trading scheme with a low allowance limit for GHG emissions, renewable power plant technologies would suddenly become cheaper relative to heavy polluters. The 5th Assessment Report by the IPCC (2014) compares the LCOE in their scenario (iv) with a carbon price of USD108.67. This would render most modern power plant technologies cheaper than the modern clean coal. Yet, this is a steep increase of the current USD5.78 and the forecasted discounted price up to 2050 at USD10.99.

The last six technologies on the list are all technologies that are not yet mature, their LCOE may drop in the coming years and this will decrease their implied abatement costs relative to clean coal.

Sensitivity analysis

Lastly, to check for the robustness of the results, we run the implied abatement costs formula using the LCA instead of the direct emissions values.

Table 5-9: LCA emission with their respective rank.

Technology	LCA emissions kgCO2e/MWh	Rank LCA emissions
Old clean coal	1088	14
Onshore wind	11	1
New clean coal	822	13
Combined-cycle gas	490	11
Nuclear	12	2
Biomass	230	10
Combined-cycle gas CCS	170	7
IGCC coal	790	12
Photovoltaic	48	6
IGCC coal CCS	200	8
New clean coal CCS	220	9
Offshore wind	12	2
Tower CSP	27	4
Parabolic CSP	27	4

Source: Author's calculations

The outcome confirms the results of this research. The implied mitigation costs values of the sensitivity analysis are similar to before. Technologies that are relatively cleaner in their LCA CO_2e emissions in comparison with the base technology, experience slightly lower values; while the opposite is true for technologies with more LCA CO_2e emissions. The ranking stays the exact same, except for the ranks of the CC gas and nuclear power plant in the old coal technology base calculation. Those two technologies were already very close together in the direct emissions calculations. Now, including emissions from gas production, uranium mining respectively, and the transport of these raw materials, the CC gas emissions experience a larger increase compared to the nuclear power technology. Thus, those two technologies switch ranks.

Table 5-10: Implied abatement costs compared to the old technology coal power plant, using LCA, in USD/tonCO_2e.

Technology	Implied abatement costs USD/tonCO2e	Rank Abatement costs
Old clean coal	Base	Base
Onshore wind	7	1
Nuclear	33	2
Combined-cycle gas	38	3
Combined-cycle gas CCS	50	4
Biomass	53	5
Photovoltaic	64	6
IGCC coal CCS	76	7
New clean coal	81	8
New clean coal CCS	90	9
Offshore wind	99	10
Tower CSP	115	11
Parabolic CSP	120	12
IGCC coal	183	13

Source: Author's calculations

Table 5-11: Implied abatement costs compared to a clean coal power plant, using LCA, in USD/tonCO_2e.

Technology	Implied abatement costs USD/tonCO2e	Rank Abatement costs
New clean coal	Base	Base
Onshore wind	cheaper and less CO2	1
Old clean coal	-81	2
Combined-cycle gas	3	3
Nuclear	18	4
Combined-cycle gas CCS	37	5
Biomass	41	6
Photovoltaic	59	7
IGCC coal CCS	74	8
New clean coal CCS	94	9
Offshore wind	105	10
Tower CSP	126	11
Parabolic CSP	133	12
IGCC coal	1097	13

Source: Author's calculations

5.6 Conclusion

This study calculates a possible carbon certificate price for several power plant technologies for Thailand, comparing the LCOE and the direct emissions of each power plant. The results show that building a clean coal power plant in Thailand is a sensible decision when comparing LCOE, direct emissions and traded carbon prices. Onshore wind energy is cleaner and cheaper to produce than energy from coal, however, the potential at these costs are not large enough to replace all of EGAT's planned clean coal power plants in Thailand. The other modern technology options are strictly more expensive, but also strictly cleaner. When comparing these technologies with the modern clean coal power plant, CC gas reduces emissions most efficiently. Yet, natural gas is not a viable option since the policy makers want to reduce the dependency of this primary energy source and have a more prudent energy source mix. Biomass, similar to wind, faces an energy potential constraint. There is a large potential, but the PDP2015 already includes most of it in its latest plan. The utility-scale crystalline-silicon PV technology is not a cheap option when considering abatement costs, this may change soon through high learning rates. Lastly, the lower half of power plants are revolutionary technologies and are not yet competitive.

The power plants are compared using the direct emissions and the LCOE, which depicts the lifetime costs of a power plant technology in per MWh. Renewable energy power plants may not be able to produce electricity all day, week or year-round, hence they are not fully comparable to the fossil fueled power plants that can be turned on and off at will. Some storage possibilities are able to distribute the excess energy supply over a 24-hour interval, but there is seasonal variation where the current technologies are not yet able to distribute large excesses in energy supply to another season efficiently. Many policymakers, energy producers and engineers are in favor of coal because of its reliance, availability and low cost. They are aware of the social costs and that the public wants cleaner energy. Thus, technologies like clean coal are introduced to address these problems. Those systems turn the fuel into electric energy more efficiently and make the combustion processes cleaner.

Nevertheless, since the costs for new technologies in the renewable energy sector are decreasing rapidly as well as for energy storage, a study comparing LCOE and direct emissions should be done every couple of years to revise this study's ranking. The cost of producing electricity from wind and solar may be reduced drastically to where these power plants are competitive to conventional coal or gas power plants, including storage. Furthermore, the LCOE and direct emissions should be assessed for the first clean coal unit to be built in Thailand's south. Lastly, more power plant technologies of the same primary fuel but with different characteristics should be added, these may include different plant or rotor sizes, or fuel sources for biomass plants.

Section 6 – Study 3

6 Feed-in tariffs for solar energy in Thailand

6.1 Abstract

FiT for solar power have been in effect in Thailand for a couple of years. In this section, effects of different levels of solar power installations from 2016 to 2036 are compared. The results are expressed in the Ft value which is the variable part of the Thai electricity tariff. Three scenarios are compared against the development plan; a non-solar case where instead of solar coal energy is generated, a medium model that increases solar power by the weighted average between the planned and the boom scenario, and the boom scenario that ends up with 30% of installed solar power installation of total grid capacity. The Ft values either feature learning or no learning and these two values are calculated as accrued or discounted Ft values. The no solar scenario shows that the government subsidizes abatement of air pollution through the solar FiT, when solar energy replaces future fossil fuel based power production. The results for the no learning case show that the subsidy may get quite costly if the government increases or abolishes the limit on the number of new solar power installed per year. A learning scenario however could replace the limit, since lowering the FiT over time in line with lower levelized costs for solar power keeps the total subsidy in check. The study uses secondary data from the PDP2015 by EGAT on the future capacity increases and energy production per year and on the levelized cost of energy from previous research on Thai power plants.

6.2 Introduction

This section examines the newly introduced FiT for solar energy in Thailand. The subsidy program is in place to introduce more renewable electricity generation, especially solar. The FiT that is mainly paid to very small power producers (VSPP) and is projected to increase the tariff which consumers pay for electricity (Pichalai, 2015).

Different scenarios of solar energy shares of the electricity mix are being compared on a US cent per kWh basis. The price per kWh of electricity neglects externalities such as pollution that may be internalized with carbon certificates. Since there are no carbon certificates on power plants in Thailand, the cost per power plant technology will only include the actual LCOE or the prevalent FiT for solar power. Additionally, the scenarios will also compare a decreasing FiT over time. The decrease stems from the learning rate on accumulated installed solar power. The costs are evaluated using the LCOE method that uses the discounted capital costs, fixed and variable operation and maintenance costs, and the fuel prices (Murray, 2009). These costs use some variables for the respective power plant's efficiency, an interest rate, the quality of coal and gas, future prices of the respective fuel, or the solar radiance respectively (Schloemer et al., 2014). The LCOE for older clean coal power plants in Thailand are from Odermatt (forthcoming). The outcome is a comparison of different scenarios of solar energy share of the fuel mix and different FiT rates, calculated either in Ft values that are paid when they occur or as net present values (NPV) of Ft that pay the full promised subsidy in the year new solar power is installed. The electricity produced by clean coal power plants will be cheaper than that of solar power plants over the time frame studied. Solar power still needs to be subsidized, which is the FiT in the case of Thailand, whereas the savings of using lower amounts of fossil fuel power times their LCOE is not as high as the subsidy. Yet over time, solar power will be cheaper than those fossil fuel based power plants due to the learning effects.

The proceeding sub-section of this section embodies the literature review, specifies the data sources and states some issues. The fourth sub-section illustrates the model used and how the yearly costs per kWh are calculated, while the fifth presents the results. In the last sub-section, conclusions to this section are drawn and possible next steps listed.

6.3 Literature review

Thailand is increasing its electricity supply over the period from 2015-2036 by almost 58,000MW, while around 25,000MW of older power plants during that time frame will be retired (EPPO, 2015c). EGAT increases the supply in order to keep up with the projected demand. Therefore, power supply needs to increase fast, however, the policy maker has also defined the new power to be stable, diversified, cheap and clean (Ministry of Energy, 2014). Fulfilling those goals puts a lot of pressure on EGAT. EGAT increases the share of clean coal in the fuel mix, this will mostly provide stable, diversified and cheap electric energy, while the FiT will help to increase the share of renewables in the electricity mix, which helps to also address the diversification issue, but also add clean energy.

Table 6-1: Total planned capacity changes in Thailand until 2036.

Total capacity in Thailand (incl. imports)	MW
Starting capacity as of December 2014	37,612
Total added capacity 2015 - 2036	57,459
Total retired capacity 2015 - 2036	-24,736
Final capacity as of December 2036	70,335

Source: EPPO (2015c)

EGAT lays out how the country and its economy will advance, how much energy conservation it targets, and which fuel sources it projects to install or retire in its PDP2015. I use those projections for my comparison. The plan presents which technologies the policy planers are supporting (The Government Public Relations Department, 2017a). The technologies include power plants using coal, gas and uranium as fuel as well as various renewable energy plants. Regarding renewable power plants, the Alternative Energy Development Plan (EPPO, 2015a) lists which type of sustainable power is going to be constructed in Thailand.

The planned installations and some of the retired capacity is not divided clearly into the fuel type by the PDP2015, they are grouped in VSPP and small power producers (SPP) types, however, with other numbers given in the appendix of the PDP2015 and by assuming the solar production of the VSPP and SPP together, we can assign the renewable power installations per year. For this we have to assume that no small-scale solar rooftop PV will be retired. A solar panel has a lifetime of roughly 30 years (IRENA & International Energy Agency Photovoltaic Power Systems, 2016), which means that any retirement would be after the studied time period.

Wangjiraniran et al. (2013) compare scenarios that have various fuel mixes. They conclude that the mix of power generation can affect the cost of electricity. Tongsopit, Chaitusaney, Limmanee, Kittner, and Hoontrakul (2015) have estimated what different levels of solar power in the energy mix could have on jobs in the PV services and manufacturing sectors. They use three different scenarios, a BAU scenario, which installs the lowest amount of solar power, a medium scenario and a domestic boom scenario where 30% of installed capacity is solar power. This study uses an adjusted version of these three scenarios and adds a no-solar scenario, where no additional solar power plant is built, but new clean coal technology generated electricity added. The BAU scenario will be as given in the PDP2015 and hence serves as the reference scenario, while the boom scenario will also assume an accumulated 30% solar PV installations of total grid capacity of the BAU scenario. The capacity factor of solar power is smaller than that of the other power plant types of which it replaces capacity. Ergo, while the total generated energy is the same in all scenarios, the total installed grid power changes depending on the technology mix. The medium scenario assumes the average of the BAU and the domestic boom. Both scenarios would be achievable if the upper limits on yearly solar installations under the FiT scheme are lifted. Tongsopit, Moungchareon, Aksornkij, and Potisat (2016) assess different business and financing models for solar installations in Thailand. They conclude that for some models, the FiT rates are very attractive and the only barrier to more solar power is the quota given by the policy maker.

The current policy for the future energy mix in Thailand is to reduce the dependency on natural gas. Clean coal is projected to be built to replace the bulk of retiring gas power plants. Hence, these three types, old clean coal technology using lignite as fuel, new clean coal technology using bituminous coal as fuel and gas power plants are considered when replacing generating capacity with additional solar PV installations. Thailand’s power mix consists of various power plant technologies that can be categorized by fuel type into large hydro above 12MW generating capacity, small hydro, solar power, clean coal of two distinct types of coal, gas, nuclear power, imports and renewables other than hydro or solar. The two types of coal are lignite and bituminous coal. The former type has a lower heating value which means it is less efficient in turning the weight of coal into electric energy. The lignite power plants use LCOE values of old clean coal power plants, while the bituminous coal fueled plants use new clean coal LCOE values. The LCOE starting rates in 2015 USD per MWh are found in the Fifth Assessment Report of the (IPCC, 2014) and Odermatt (forthcoming), while the FiT rates are given by the EPPO (2015b). No premium for location or diesel replacement have been included in the FiT. LCOE for renewable power plants are from a recent report by IRENA (2016b). Subsidies, taxes, and insurance costs are not considered for the power plants’ LCOE. Costs for infrastructure other than the power plant itself are also not included in the LCOE. Unlike conventional power plants using coal, gas, and uranium; most renewable power plants have no fuel costs and relatively low O&M costs. Consequently, capital and installation costs, are major cost drivers. The capital costs also include financing costs. Likewise, the amount of solar irradiation influences a project’s viability to a point that these power plants cannot be built just at any location. Hence, higher LCOE in some countries do not necessarily mean inefficient capital cost structures.

The Energy Research Institute is actively studying the effects of the government’s policies on renewable energy. Tongsopit and Greacen (2013) dissect the adder program for renewable energy that was adopted by the Thai Cabinet in 2002 and implemented in 2007. The paper further shows how Thailand’s energy generating landscape is organized. There are three main energy producers, EGAT, independent domestic power producers, and imports. EGAT mostly produces base load power with coal and gas power plants, some renewables with large hydro power plants and some other renewable power. The current energy imports are produced from gas from Malaysia and hydro energy from Laos, while there will be future hydro imports from Myanmar as well. Lastly, the independent domestic power producers are divided up into groups depending on their size. The sub-group, independent power producers, consists of mostly utilities with large generating capabilities of more than 90MW. SPP have generating capacities of between 10-90MW, and VSPP use generators that are smaller than 10MW. The solar power installed is mostly in the SPP and VSPP group. The initial subsidy to renewables was called adder which is a premium FiT that adds a subsidy on top of the electricity tariff, then a new subsidy structure for solar energy was set in place in 2013 (Tongsopit et al., 2016), then rates were adjusted slightly in 2014. This new solar specific subsidy is called FiT, and its tariffs are used for this study's calculations of costs. The FiT is a subsidy that pays a fixed amount, independent of the current electricity tariff (Kurovat, 2012), which results in lower financial risks for both the end-consumer and the developer. The new FiT's purpose is to give strong incentives for rooftop solar PV installations, since Thailand's solar energy was dominated by utility-scale PV at that time.

The FiT has different rates for certain levels of capacity. The lowest capacity generator on residential rooftops receive the highest rate at about USD200 per MWh. Commercial rooftop developments receive rates depending on their size. In this study, there is no distinction done between the two rates for the commercial rooftop FiT, but a weighted average is used that computes to a bit more than USD180 per MWh, while solar farms and cooperatives with a generator of maximal 90MW, 5MW respectively, receive just over USD165 per MWh. The supporting period is 25 years and adjusted for inflation over time.

Table 6-2: FiT rates, in USD/MWh.

Solar technology type	2016	2017
Residential PV	203.2	200.0
Commercial PV	181.2	181.2
Utility-scale PV	165.2	165.2

Source: Sathienyanon (2015)

The scenarios mentioned use LCOE for the three fossil fuel technologies versus the FiT rate for solar power. By 2025, levelized costs for solar PV may decrease around 59% compared to 2015 (IRENA, 2016b). Hence, a different setup where the FiT decreases for new installed capacity over time may be more attractive. This could be achieved with a market-based approach (Lesser & Su, 2008). Therefore, this study also includes adjusting factor for the FiT. This adjusting factor is called the learning rate. A specific learning rate decreases the price of a good by a certain percentage for each doubling of its production, or installed capacity in the case of power plants. Rubin et al. (2015) state the learning rate formula and give mean learning rates for old and new clean coal and gas power plants over several studies. The learning rate for solar PV is estimated by IRENA (2018).

Table 6-3: Median learning rates for a doubling of installed capacity.

Learning rates	
Old clean coal	8.3%
New clean coal	8.3%
Natural Gas	14.0%
Solar PV	35.0%

Source: Rubin, Azevedo, Jaramillo, and Yeh (2015) and IRENA (2018)

In Thailand, the subsidies are paid with the variable fuel adjustment charge Ft. Hence, to calculate the impact on the end consumer, an Ft per year needs to be estimated. The fuel adjustment charge is estimated every 4 months, but since the PDP2015 only forecasts yearly capacity increases and plant retirement, I will have to use a yearly Ft. The calculation for the Ft follows Pita, Tia, Suksuntornsiri, Limpitipanich, and Limmeechockchai (2015) where they divide the subsidy value by the total grid generating capacity. In their paper, the authors examine the subsidy cost side, while this study also offsets the subsidy with the costs saved on producing less electricity with old and new clean coal and gas technology, resulting in the net-subsidy. The results give two types of Ft values. One Ft estimation uses an Ft that is paid in the year that the Ft is due. This shows the direct cost of energy to the end-consumer in that specific year. Another Ft estimation applies the NPV method. It calculates the cost of the Ft value in that year as if the net-subsidy is paid for the whole supporting period of 25 years in the year the additional solar PV has been build.

There are different energy prices depending on the amount of consumption. The current price format for a household in Bangkok consuming 250kWh is 12.41 US cent/kWh. According to the Metropolitan Electricity Authority (2018) 1.2 type household, a household consuming up to 150kWh per month is paying 10.36 US cent per kWh and 13.45 US cent per kWh above up to 400kWh. There is a fix rate for the service charge of 121.87 US cent, and an Ft charge, which currently is negative at -0.51 US cent. Lastly, a tax of 7% is added on top of the total. In comparison, for a low-income household in Bangkok using 100kWh per month, we get 11.10 US cent/kWh.

To calculate the actual energy produced, certain capacity factors need to be assumed, for solar PV panels we are assuming a capacity factor of 16.6%, which is the capacity factor of a solar project in Lopburi, Thailand (Asian Development Bank, 2014), while for both clean coal technologies and gas power, we assume an 85% capacity factor (Kamsamrong & Chumnong, 2014). Therefore, the 30% accumulated installed solar PV panels in the boom scenario does not replace a full 30% of installed fossil fuel power, only about a fifth. Solar PV are not reliant on direct solar irradiance, because it can also use diffuse solar irradiation (IRENA, 2012c). This makes the technology available everywhere in the world. In Thailand, the total solar radiation is around 1,700-1,900 kWh/m^2 (Janjai et al., 2013). Another assumption is that solar energy produced in the model can replace other energy. Luckily, for solar energy, the periods of production and no production coincidence with peak electricity demand by month (EPPO, 2017) because of the energy used for cooling in the hot season as well as by the time of the day, as more energy is used during the day. PV power plants are still relatively expensive compared to clean coal. The technology experiences zero emissions, but its LCOE are still more than 50% higher than modern clean coal power. Furthermore, it may experience issues in its energy availability and the prevalent solar quality. However, the power potential is large, estimated at over 40GW (Achawangkul, 2015a). This will not be reached by the boom scenario, but it could pose a problem after the studied time frame. However, on the other side, there is a benefit of not having a fuel that needs to be bought, this makes the technology independent on the future fuel price.

However, fossil fueled power plants are not truly comparable to solar power without any assumptions. A solar PV panel may only produce electricity during certain times of the day on which it may produce excess electricity and without any storage or distribution on the grid, this may lead to curtailments and an efficiency decrease of the renewable power plants (United States Department of Energy, 2015b). Storing electricity renders solar energy more expensive. Therefore, it is necessary to decouple electric energy demand and supply (Carrasco et al., 2006), this turns these power plant types comparable on the cost basis used in this section. Also, we assume that the Thai power grid will be able to handle decentralized electricity production that arises with more solar PV installations (Battaglini et al., 2009). On the other side, decentralized electric energy production may also reduce transmission line losses and costs (Masters, 2004).

6.4 Model

The models in this study are from Pita et al. (2015) and Tongsopit et al. (2015). The first paper compares the subsidies in Thailand over time using the previous power development plan. This research builds on this and additionally subtracts the lower electricity output from old and new clean coal and gas power plants. The second paper is the base for the different scenarios used. The results are a comparison of subsidy amounts over distinct levels of installed solar PV capacities. First, the installed capacities need to be estimated to calculate the LCOE of future power plants, then the produced energy needs to be estimated in order to then calculate cost and savings in US cents per kWh. The net-subsidy is then divided by the total grid generating capacity to obtain the accrued and discounted Ft values.

The learning curve is calculated as in Rubin et al. (2015) and is denoted in USD/MWh, with constant 2015 US dollar, which we use for all dollar values in this section.

$$Y = ax^b$$

Here, Y is the future cost of technology after learning-by-doing has decreased the LCOE, FiT respectively, of that particular technology. This is calculated by multiplying the initial costs, a, with a certain increase of the cumulative installed capacity over the initial capacity, $x = \frac{cumulative\ installed\ capacity}{initial\ installed\ capacity}$, raised to the power of the rate of cost reduction, b. We can derive the parameter b using the learning rate formula.

$$z = 1 - 2^b$$

$$b = \frac{\log 1 - z}{\log 2}$$

The learning rate formula can be restated to calculate the rate of cost reduction, b, by using given learning rates z. Hence, the future cost of a technology i on its learning curve is calculated by the formula below.

$$Y_i = a_i * \left(\frac{cumulative\ installed\ capacity_i}{initial\ installed\ capacity_i}\right)^{\frac{\log 1 - z_i}{\log 2}}$$

The data for the learning curve are from Odermatt (forthcoming) on the initial LCOE and from EPPO (2015b) for the FiT rates on solar power. The PDP2015 provides the values of installed capacities over time, while Rubin et al. (2015) provide the learning rates for coal and gas power plants. In the case of solar power, we either assume no learning for the FiT rates or take IRENA’s (2018) solar learning rate.

Each scenario has different installed capacities, which in turn renders lower and higher LCOE, FiT respectively. In this study, solar power additions replace additions of old and new clean coal and gas power in this order, meaning if there is new gas and old clean coal technology additions in the same year, then less of the old clean coal technology is added to the grid; if there is more solar added than old clean coal, then also a lower gas power capacity is added to the total capacity. In the case no new generating capacity of those three types are added, then the newly built solar capacities are added up and subtracted from the next capacity increase of one or more of those plants. The capacity additions from the BAU scenario for technology $i = old\ clean\ coal, new\ clean\ coal, gas$ in year j are subtracted by the solar capacity additions in one of the other scenarios, this renders the actual capacity addition in that scenario.

$$capacity\_additions_{i,j} = capacity\_additions\_bau_{i,j} - capacity\_additions_{solar,j}$$

The BAU scenario uses installed capacities from the PDP2015, while the boom scenario uses a target of 30% for solar PV generating capacity in 2026 of total BAU installed capacity in that year. The boom scenario assumes that 40% of the total increase of solar PV capacity by 2036 is installed by 2020 and an increase of two thirds over 2015 is achieved by 2025. This increase is analogous to the total installed power by those years respectively. The increases between the 5 and 10-year intervals are smoothed out. In the medium scenario, the total installed solar power is the average of the BAU and boom scenario for each year. There are different levels of FiT for different locations and sizes of solar PV installations. The lowest payout is for utility-scale plants. We assume these power plants' accumulated installations increase by 2.3% compounded annually in the BAU scenario, according to the similar scenario in Tongsopit et al. (2015), while in the boom scenario, the annual compounded additions are double the BAU rate, and the medium scenario assumes the average of those two. The remaining power is divided up evenly between residential rooftop installations and commercial rooftop installations, except for the first year, where commercial rooftop get three quarters of the remainder. The initial distribution of values are from the Thai Policy Brief by the GIZ GmbH (2016).

This defines installed power and costs, now energy production needs to be calculated. The PDP2015 lists the expected electricity production per each year and technology. This is used for the BAU scenario. The boom and medium scenarios are adjusted according to their increased solar PV energy production.

The additional power installed per year is multiplied by the hours per year and the capacity factor for solar PVs in Thailand. This transforms the capacity additions in year j to energy additions in that year.

$$energy\_additions_{solar,j} = capacity\_additions_{solar,j} * \frac{hours}{year} * efficiency_{solar}$$

Then this increase decreases old and new clean coal or gas by the same amount of energy. The decrease in additional energy follows the procedure above for the power case. However, for the last condition, where no new generating capacity of those three types are added, then the old clean coal electric energy production is reduced. Thus, the net-subsidy is the FiT subsidy reduced by a lower production in one or more of those three technologies.

$$energy\_additions_{i,j} = energy\_additions\_bau_{i,j} - energy\_additions_{solar,j}$$

Hence, I am using Pita, Tia, Suksuntornsiri, Limpitipanich, and Limmeechockchai's (2015) formula on subsidies, but subtracting the savings of the same amount of electric energy resulting in the net-subsidy from FiT.

$$subsidy_{FiT} = re_{electricity} * (fit - tariff)$$

$$savings_{FiT} = \left(-non\,re_{electricity}\right) * (lcoe - tariff)$$

In the case where $re_{electricity} = non\,re_{electricity} = electic\;energy,$ we get a transformed formula for net-subsidies.

$$net\;subsidy_{FiT} = electric\;energy * (fit - lcoe)$$

The net-subsidy is of that specific year is used to obtain the Ft value, the uniform variable fuel adjustment tariff in Thailand. The yearly Ft value is in US cent per kWh and is calculated by dividing the year's subsidies net its savings by the total generated electric energy.

$$Ft_{FiT} = \frac{electric\;energy * (fit - lcoe)}{grid\;generation\;of\;Thailand}$$

Each year's Ft values are added to the next years. The FiT program runs for 25 years, which means, even after the PDP2015 time frame, the accrued Ft value keep accumulating and the consumers keep paying the net-subsidy.

$$Ft_{FiT,t}^{SUM} = \frac{\sum_{t=0}^{T} electric\;energy * (fit_t - lcoe_t)}{grid\;generation\;of\;Thailand_t}$$

There will be two yearly Ft values to list the yearly effect of the subsidy on end-user prices, in the years 2016-2036 for both studied solar PV addition scenarios. One of those Ft values include learning. This means that each year, the policy maker decreases the FiT rate for solar capacity additions in the following year. The decrease is equal to the learning curve value. The other Ft value does not feature learning; hence, the FiT rate is the same over the whole period.

Another two Ft value lists are calculated taking the FiT rates for the whole supporting period of the program into account. Which means that each year, the net-subsidy of that year's new solar power installations is added up over the discounted values for the next 25 years, with a discount rate of $\rho = 10\%$ (Tongsopit et al., 2016).

$$Ft_{FiT,t}^{NPV} = Ft_{FiT,t} * \frac{1-(1+\rho)^{-25}}{\rho}$$

This gives us the discounted costs of the subsidy program for each year. Therefore, we get an Ft if we would want to compensate the solar PV investor within one year instead of over the next 25 years. We can then see the total costs to the consumers without moving some of the costs to later stages or out of the period studied.

Finally, conducting the sensitivity analysis with different parameter values reveal comparable results to the ones studied for the discussion part. The parameters tested are, changes in the capacity factor for power plants, different discount or learning rates, using the LCOE for solar instead of the FiT, or different weights of installation for residential, commercial and utility-scale power plants.

6.5 Results

Intermediate results

In order to get the results on the fuel mechanism surcharge, the flow of power plant type installations need to be identified, the power installed per scenario and per plant needs to be calculated, the decreasing LCOE calculated with the learning rate and the energy that is replaced computed.

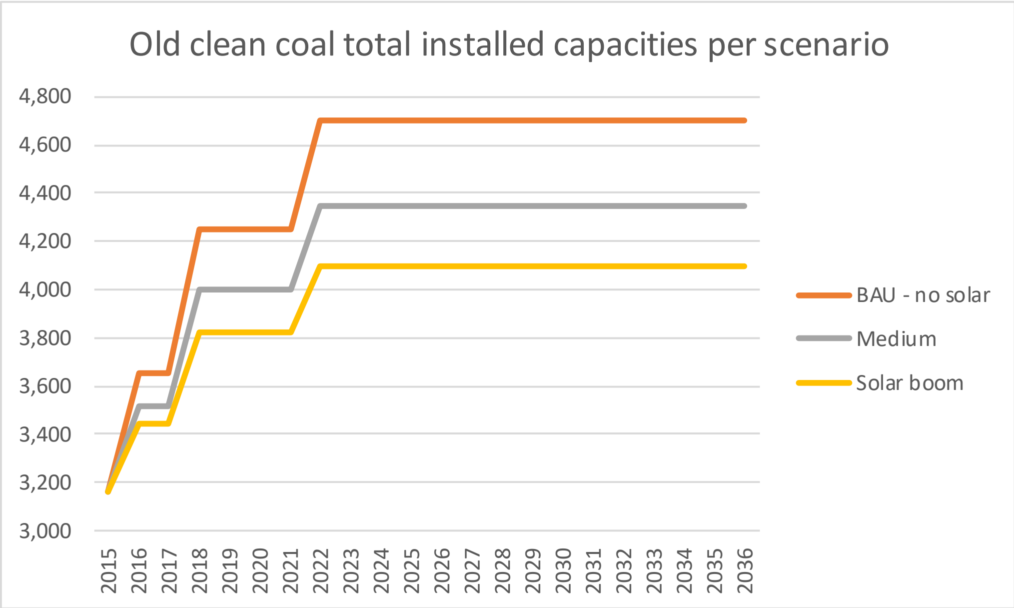
The BAU scenario is mostly taken from the PDP2015. The data has been put together in a Jupyter Notebook (Kluyver et al., 2016) and then exported to Microsoft Excel for further calculations. The Jupyter Notebook is written in Python 3.6 (Python Software Foundation, 2018) and is on Github (Odermatt, 2018).

The technologies that are consider are old and new clean coal, natural gas, and solar power; solar power is then divided into three groups again, they are PV residential rooftops, PV commercial rooftops, and PV utility-scale power. Figure 6-1 up to Figure 6-7 display the installed capacities for 2015 with the additional increases in yearly generating power. The values are all increasing because the power plants that are being shut down are not accounted for. The learning curve only considers newly added power, whereas when a power plant is shut down, the learning curve does not decrease in learning.

The first of these figures show the increase in old clean coal technology. The BAU scenario is the same as the no solar case. They experience the highest installed capacity, while the other two cases mitigate some of the power installation increases.

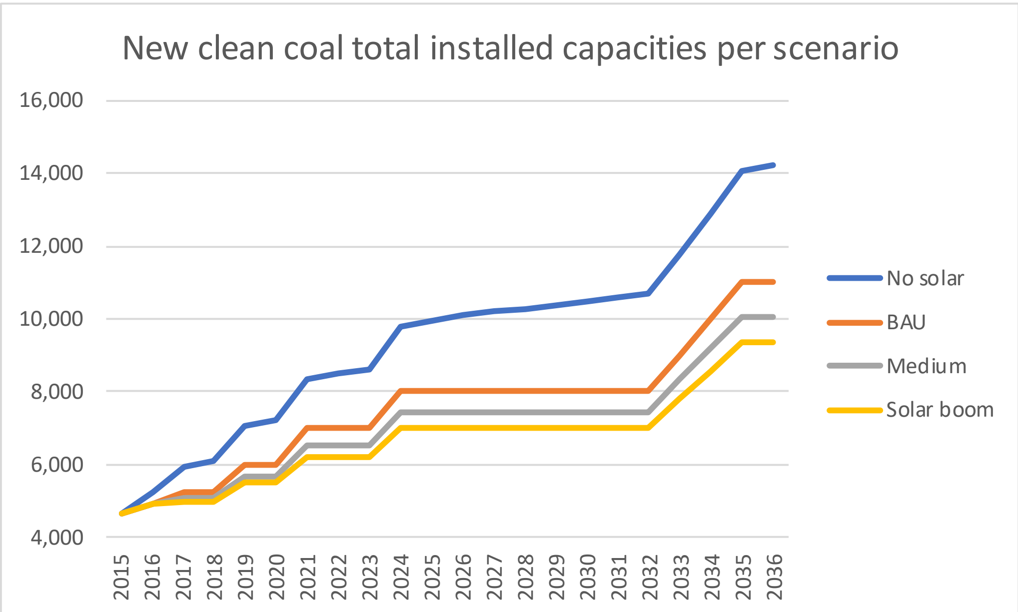
As stated in the model section, the old clean coal power technology is the technology that is chosen first to decrease newly installed capacity. In the boom case, a reduction of 600MW by 2036 compared to the BAU case can be achieved which is almost a full plant size of an old clean coal power plant that could be scrapped (Hongsa Power Company Limited, 2013). There are more clean coal power plants to be built, see Figure 6-1 below, therefore, the difference between the BAU and boom scenarios are a bit larger at around 1,700MW, which are around two power plant units. In the no solar scenario, new clean coal power replaces the solar power to be installed in the BAU scenario, hence there is about 3GW more new clean coal power installed in this scenario.

Figure 6-1: Old clean coal total installed capacities per scenario, in MW, with a lower bound on the y-axis at 3,000MW.



Source: Author's calculations

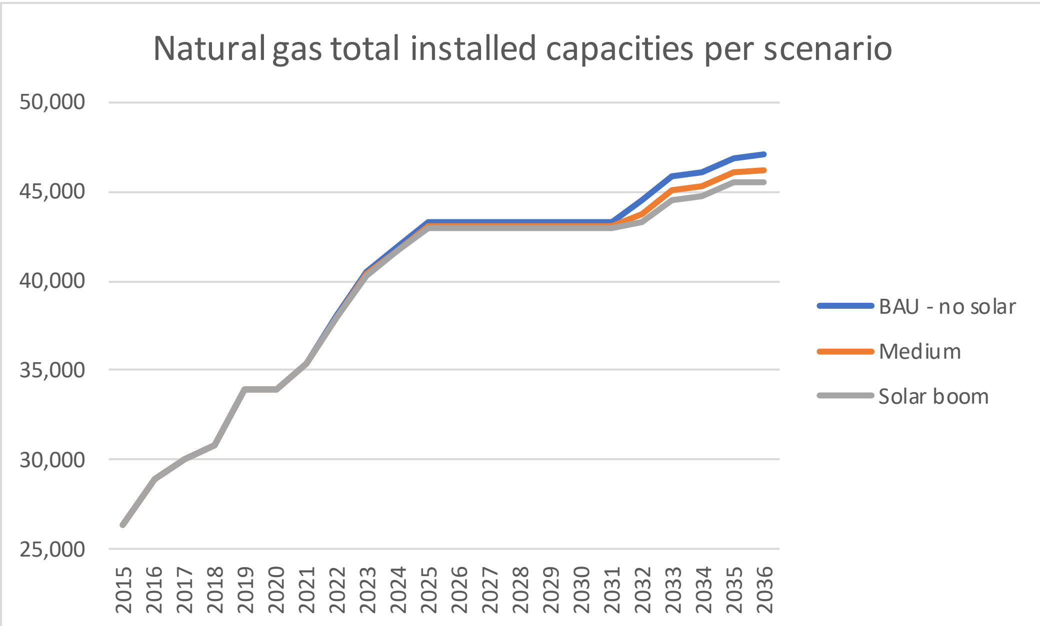
Figure 6-2: New clean coal total installed capacities per scenario, in MW, with a lower bound on the y-axis at 4,000MW.



Source: Author's calculations

The natural gas technology is replaced by solar when there are now old or new clean coal technology being built in that year, or the newly added generating energy by solar power is larger than those two technologies together. This occurs towards the end of the timeframe along with a decrease in needed natural gas power of around 1,600MW. The increase of natural gas power seems to be steep in the figure below, however, the graph depicts only newly installed capacities. Thailand relies heavily on gas power; hence several older natural gas power plants are decommissioned in the next 20 years. The effect of decommissioning older gas power plants will be seen in the case of energy produced.

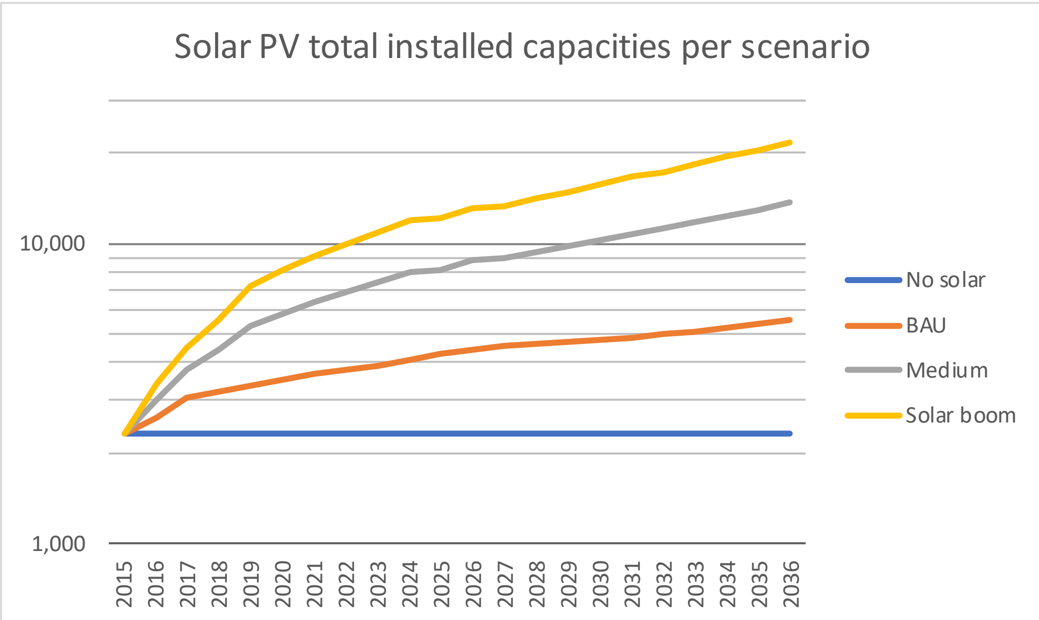
Figure 6-3: Natural gas total installed capacities per scenario, in MW, with a lower bound on the y-axis at 25,000MW.



Source: Author’s calculations

The next couple of figures illustrate the solar scenarios. The first figure describes the overall solar PV installations over time on a log-scale with basis 10. A log-scale was chosen to characterize the speed of solar installations. The BAU case simply draws the power installations given in the PDP2015. The boom scenario is the scenario where solar power constitutes 30% of installed generating BAU power by 2035. The curve of the boom case follows the installed capacity of all power plant technologies of the BAU scenario in 2020 and 2025 versus the total capacity by 2036. The values in between are smoothed out average increases. About half of the newly installed capacity is going to be built by 2021. Thus, in the figure below, where new solar power installation is shown, installed capacity quadruples by 2021 from the initial year 2015, while it only doubles from there on to the end of the period. The medium scenario is just halfway between the BAU and the boom scenario. In the no solar case, where no more solar power is installed, the solar PV capacity stays flat.

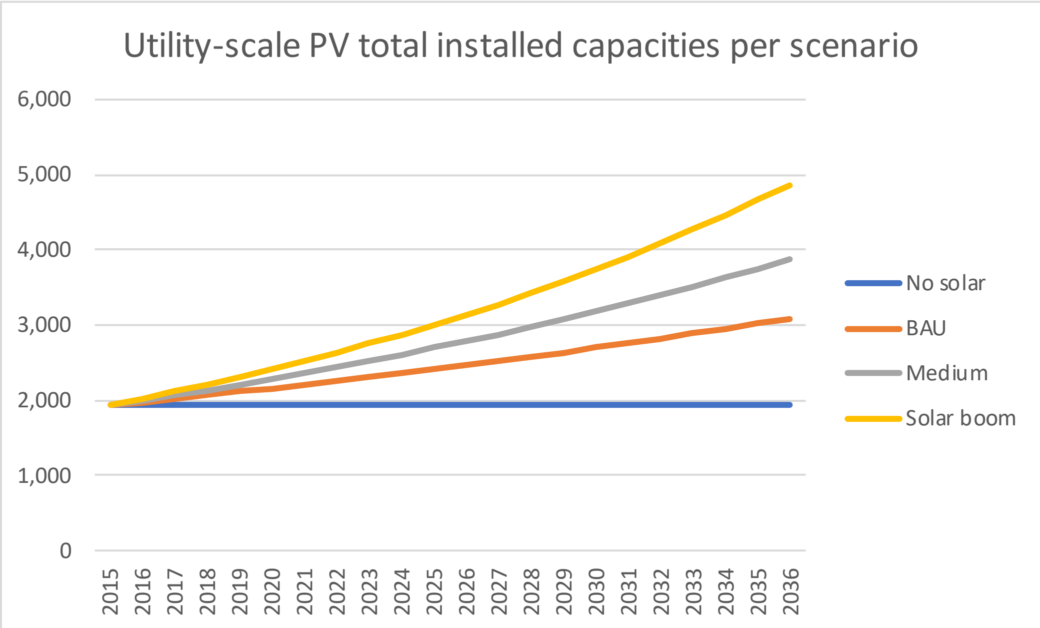
Figure 6-4: Solar PV total installed capacities per scenario, in MW, log-scale, with a lower bound on the y-axis at 1,000MW.



Source: Author's calculations

Solar power is divided into three categories, residential rooftops, commercial rooftops, and utility-scale PVs. Utility-scale solar power was the main installed type by 2015, with 83% installed of the total. The policy maker introduced the solar FiT in order to increase the share of rooftop PVs. The yearly increase of utility-scale PV is a compounded 2.3% in the BAU case, in line with the paper that features the different scenarios (Tongsopit et al., 2015). In the boom case utility-scale solar PV increases by double the BAU compounded yearly rate, while in the medium case it is the weighted average of the two scenarios. Ergo, we have these exponential growth curves below. Lastly, the in the no solar case, the curve stays flat at the 2015 installed capacity value.

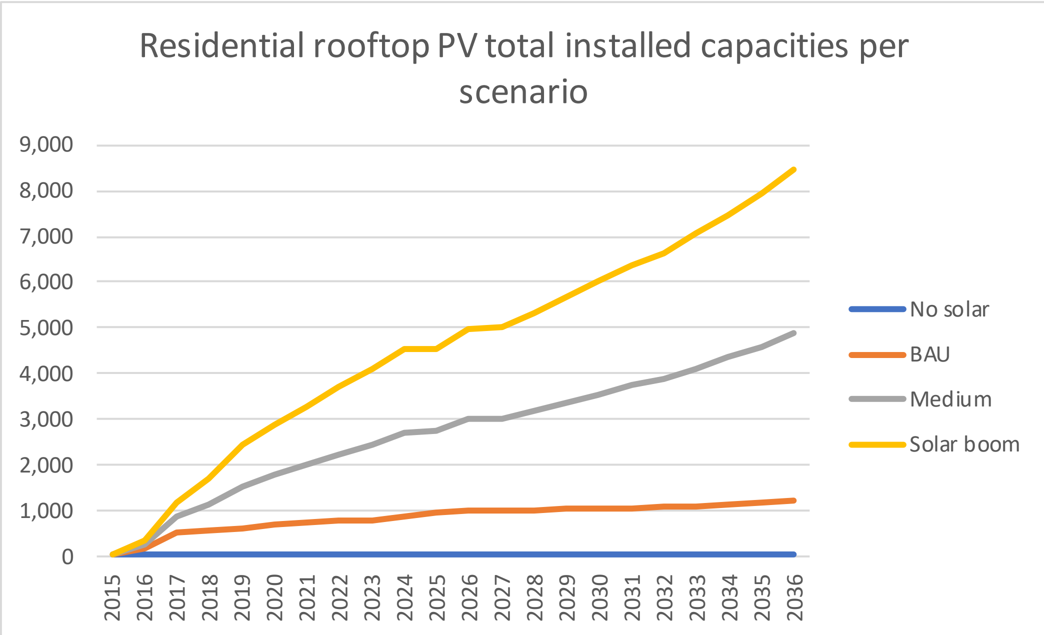
Figure 6-5: Utility-scale PV total installed capacities per scenario, in MW.



Source: Author's calculations

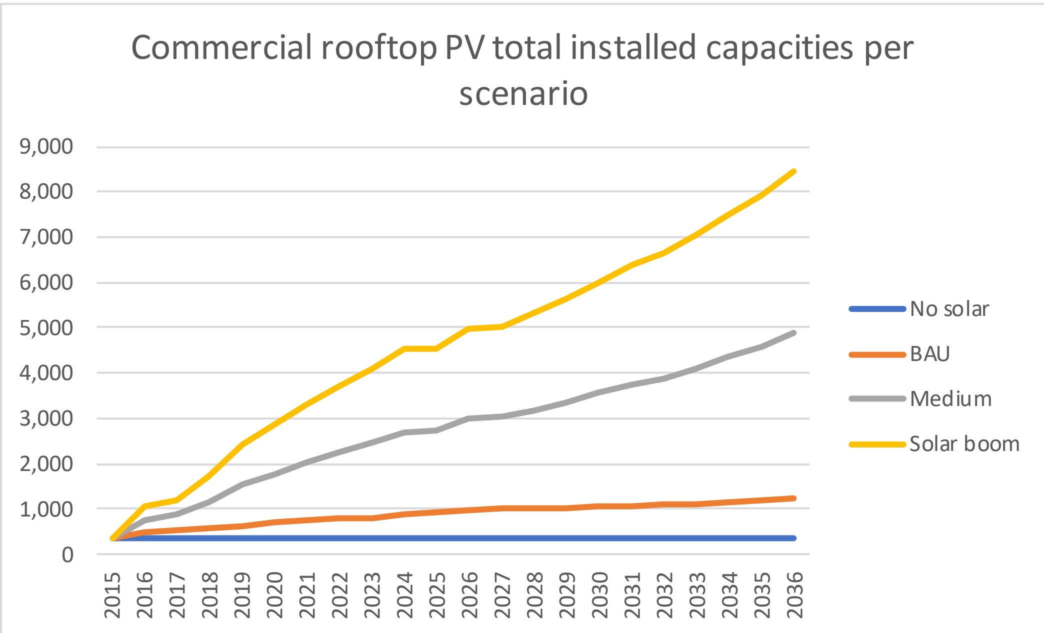
In the no solar and the BAU scenarios, utility-scale PV remains the largest PV type block in Thailand. However, this changes under the medium and boom scenarios when the two rooftop PV types overtake utility-scale PV in the early years of the program.

Figure 6-6: Residential rooftop PV total installed capacities per scenario, in MW.



Source: Author’s calculations

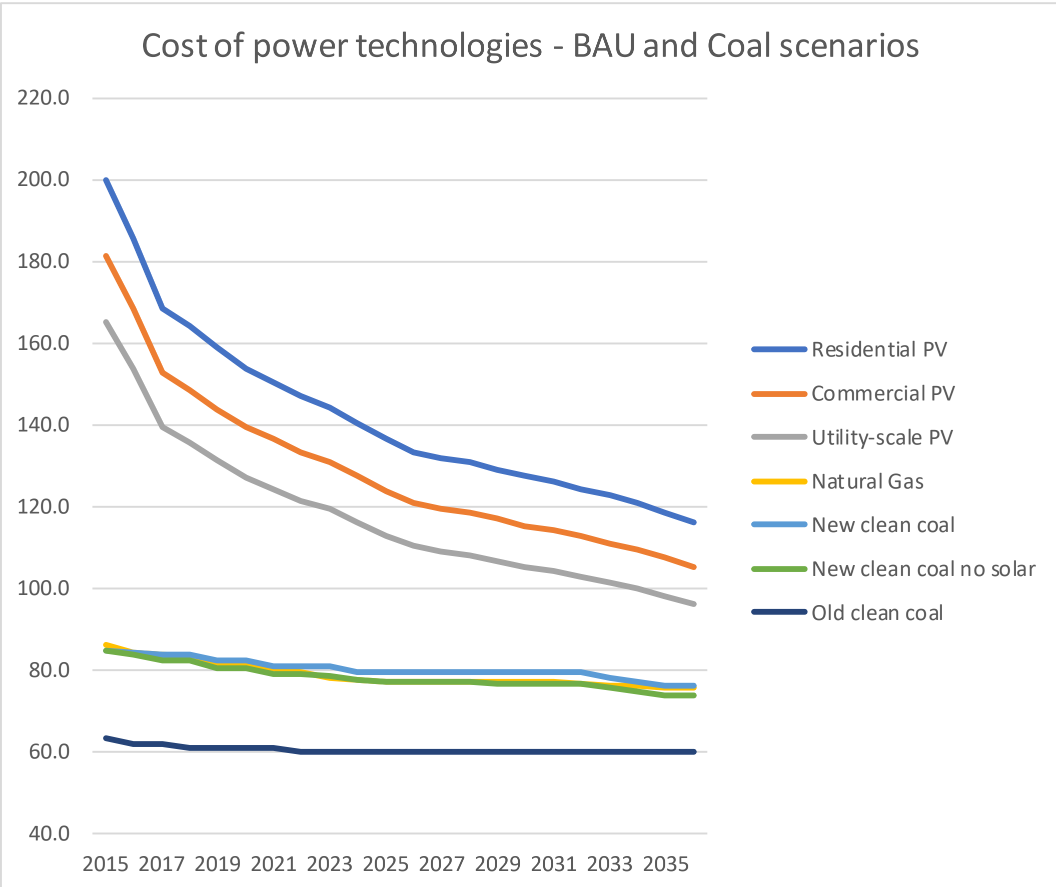
Figure 6-7: Commercial rooftop PV total installed capacities per scenario, in MW.



Source: Author’s calculations

The next three figures show the cost per MWh changes over time due to the learning effect of the power plants. Figure 6-8 constitutes of the BAU scenario and the LCOE of new clean coal in the no solar case. In the no solar case, there is no solar PV built, hence there is no FiT costs. Old clean coal and natural gas develop in line with the BAU case. However, new clean coal replaces the solar installations from that would be added in the BAU case, so solely new clean coal's LCOE change in the no solar case. There is only about 3GW of solar power built in the BAU case, thus, the additional costs decrease due to learning is not that great.

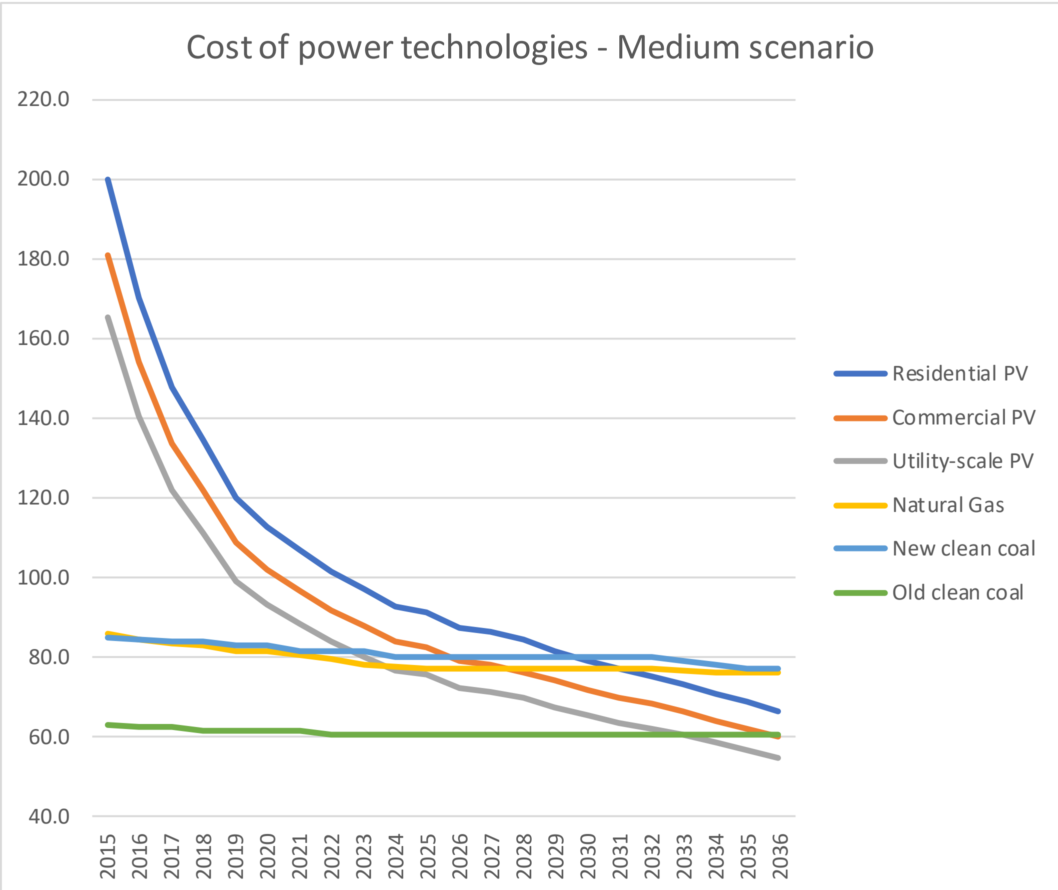
Figure 6-8: Cost of power plant technologies for the BAU scenario and the no solar scenario for new clean coal, in USD/MWh.



Source: Author's calculations

The solar FiT is quite large in the early years. In the BAU case, the additional units of solar power in each solar PV type is not large enough to have decreasing costs that would come close to new clean coal's LCOE. In the medium scenario in Figure 6-9 below, the solar subsidy costs per MWh produced decline to below the new clean coal and gas LCOEs, and the old clean coal LCOE for the utility-scale PV type. Therefore, the subsidy over clean coal is lower in the medium case against the BAU case in the early years, to even cheaper over the other three non-solar power plant types in the later years. This means that in the last couple of years, the subsidy is actually a cost saver.

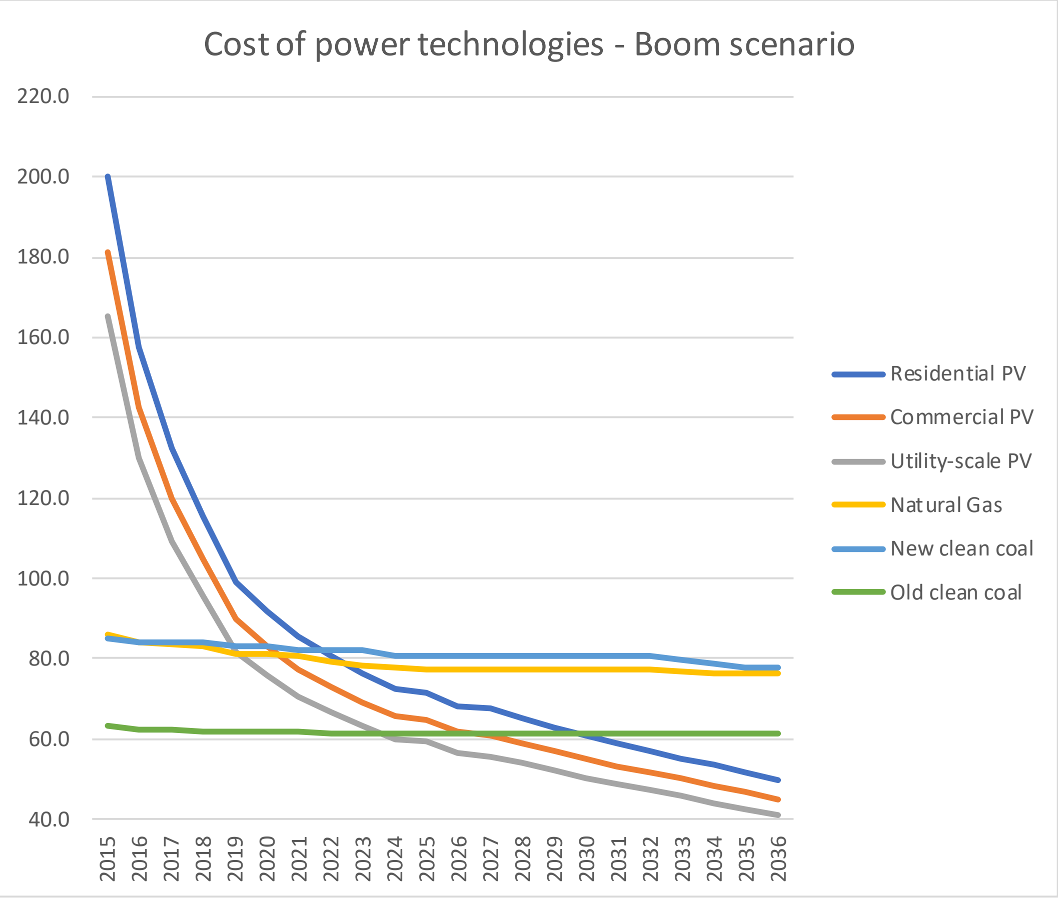
Figure 6-9: Cost of power plant technologies for the medium scenario, in USD/MWh.



Source: Author's calculations

The boom scenario is similar to the medium scenario, except for a faster drop in the subsidy costs per MWh and the differences between the solar type subsidy costs is reduced as well. Furthermore, all three subsidy types are cheaper than old clean coal by around 2030.

Figure 6-10: Cost of power plant technologies for the boom scenario, in USD/MWh.



Source: Author's calculations

The next step is to calculate the predicted energy supply per each scenario. The BAU scenario is taken from the PDP2015 and the others are adjusted dependent on the solar power installed in each year and on which other technology is replaced. In the BAU scenario, old clean coal and gas power plants contribute less in accumulated energy to the total supply in total values, while new clean coal and solar PV expand their total supply. Old clean coal power supplies the least electric energy to the grid in 2015 and this would decrease to half that by 2036 in the boom scenario compared to the BAU case. New clean coal technology's supply contracts by about the same amount but has a higher base in the BAU case in 2036. As mentioned before, it would replace solar power in the no solar case, and therefore its supply in the no solar case would increase by about 5,000 gigawatt-hours (GWh). Natural gas power is the main contributor to the power grid in Thailand in the base year and it remains there until the end of the timeframe studied. The decrease of energy supply from the BAU to the boom case is the lowest, however, this is due to the setup of the model. The model lessens the input by the dirtiest technology first. If a very strong political will by the policy maker to decrease electricity production by natural gas is assumed, then the natural gas supply in 2036 would decrease to almost 100,000GWh.

Table 6-4: Accumulated generated energy per scenario of old and new clean coal, natural gas and solar PV in the base and final year, in GWh.

Old clean coal	2015	2036	New clean coal	2015	2036
No solar	20,183	19,341	No solar	18,287	59,089
BAU	20,183	19,341	BAU	18,287	54,365
Medium	20,183	14,585	Medium	18,287	49,612
Boom	20,183	9,828	Boom	18,287	44,859
Natural gas	**2015**	**2036**	**Solar PV**	**2015**	**2036**
No solar	123,508	120,194	No solar	3,378	3,378
BAU	123,508	120,194	BAU	3,378	8,103
Medium	123,508	117,838	Medium	3,378	19,969
Boom	123,508	115,481	Boom	3,378	31,834

Source: Author's calculations

Results

The results are divided up into four parts. First, we compare how much the government may be able to save versus the BAU scenario, meaning the policy maker does not implement the FiT but rather invests more into clean coal capacity. Second, the net-subsidy that does not feature learning for the boom scenario is listed. Then, the accrued Ft payments list is described, where the Ft is paid in the year the net-subsidy is paid in, hiding some of the true costs. Lastly, we examine the true costs of the net-subsidy with the NPV method.

In Table 6-5 below possible savings in US cents per kWh of total grid generation in Thailand are shown. This scenario depicts the possible cost savings of not installing any additional solar PV, or in other words, not implementing the FiT and replacing the electric energy that solar would have produced with clean coal. Clean coal has been chosen as the sole replacing technology, since it is one of the favored technologies by the policy maker in the PDP2015. It is also the cheapest, albeit dirtiest, option. New clean coal power additions are 3,236MW by 2036, while 4,724GWh of coal energy is produced additionally by that year. The Ft_sum column is the cost savings of the end-user per year. It is increasing over time, since the previous cost savings are accumulated in the next years, up to 25 years.

Table 6-5: Savings if no additional solar installation, but clean coal instead, Ft in US cents/kWh.

Year	Ft_sum	Ft_npv	Year	Ft_sum	Ft_npv	Year	Ft_sum	Ft_npv
2016	-0.02	-0.20	2023	-0.10	-0.07	2030	-0.13	-0.04
2017	-0.06	-0.32	2024	-0.11	-0.09	2031	-0.13	-0.04
2018	-0.06	-0.08	2025	-0.12	-0.11	2032	-0.13	-0.05
2019	-0.07	-0.11	2026	-0.12	-0.08	2033	-0.14	-0.05
2020	-0.08	-0.10	2027	-0.12	-0.04	2034	-0.14	-0.06
2021	-0.09	-0.08	2028	-0.12	-0.03	2035	-0.14	-0.06
2022	-0.09	-0.08	2029	-0.13	-0.04	2036	-0.15	-0.08

Source: Author's calculations

The second column, Ft_npv, depicts the discounted values of clean coal generation replacing solar PV energy. We can see large cost savings in the beginning where more solar power plants are being built. The Ft_npv value does vary around -0.10 US cent per kWh because this method does not defer subsidy and savings values to later years, but assumes cost for the year that it is depicted in. In this scenario, the Ft_npv value mostly depends on the solar generating capacity that is being replaced by clean coal energy production.

This first scenario is cheaper than the BAU scenario that the PDP2015 lays out, but also pollutes more. The scenarios in Table 6-6 up to Table 6-8 below consider cleaner options, where the policy maker allows for more solar PV installations to be built with and without reducing FiT rates.

Table 6-6: Boom accumulated Ft and boom discounted Ft without learning, Ft in US cents/kWh.

Year	Ft_sum	Ft_npv	Year	Ft_sum	Ft_npv	Year	Ft_sum	Ft_npv
2016	0.07	0.65	2023	0.47	0.45	2030	0.64	0.45
2017	0.12	0.47	2024	0.51	0.47	2031	0.68	0.45
2018	0.20	0.75	2025	0.49	-0.03	2032	0.70	0.29
2019	0.29	0.90	2026	0.54	0.52	2033	0.73	0.40
2020	0.34	0.49	2027	0.54	0.10	2034	0.76	0.42
2021	0.38	0.49	2028	0.57	0.39	2035	0.80	0.44
2022	0.43	0.55	2029	0.60	0.43	2036	0.84	0.49

Source: Author's calculations

Table 6-6 shows the case for no learning of the FiT rates, which means that the FiT is not adjusted to future LCOE decreases due to lower solar panel costs, higher capacity factors, and lower installation cost. The table features estimates for the accrued Ft over time and each year's NPV Ft for the boom scenario only. The medium scenario is about half of the boom Ft values because of the way the medium values are being computed. The Ft_sum values are increasing over time, since the newly added installations increase the Ft steadily, while a decrease in the Ft_sum could only happen after the 25-year period of support. This means that a lot of the cost actually accrues after 2036 and is not depicted in that column. The true cost of the net-subsidy is displayed in the Ft_npv column of Table 6-6. In this column, the net-subsidy for each year is calculated as its NPV. Hence, this value is negative, if either there is less additional solar PV installed in the respective scenario versus the BAU scenario, or the FiT costs are lower than the LCOE of the non-renewable power plant that balances out the increase in solar energy production. The Ft values in the beginning are larger than in or after 2025. This is because of a reduction of the speed of new additions to the existing solar PV stock. The Ft_sum column results is the reason why the policy maker has a maximum limit on the amount of new solar power that can be added in a specific year, or phase respectively. It shows that costs might explode over time. In 2036, the Ft_sum value paid is at 0.84 US cents per kWh already. For a low-income family using around 100kWh per month, the Ft_sum value is 7.89% of the current tariff for this consumer group, excluding the service charge, Ft and tax (Metropolitan Electricity Authority, 2018). This is a painful increase in the electricity bill.

The accumulated solar power installed by 2036 in the boom scenario is 21,804MW, which is about four times the value in the BAU case in the same year. The additional energy produced by solar is 23,732GWh and coincides with a reduction of the same size in electricity produced by the non-renewable technologies. The reductions in detail are 10GWh by both, the old and new clean coal technologies and by almost 5GWh by the gas technology. Assuming an 85% capacity factor, solar in the boom scenario replaces about two 600MW units in each coal technology and one unit of a natural gas power plant.

Instead of the mentioned quota on the maximum new solar power installation per year, the policy maker could reduce the FiT rates each year, depending on the newly realized LCOE of solar power in the last year. A learning rate that decreases LCOE 35% on each doubling of the accumulated capacity is assumed. The results are illustrated in Table 6-7 below.

Table 6-7: Ft for yearly accumulated payments with learning, Ft in US cents/kWh.

Year	Ft_med	Ft_boom	Year	Ft_med	Ft_boom	Year	Ft_med	Ft_boom
2016	0.03	0.05	2023	0.09	0.10	2030	0.09	0.08
2017	0.04	0.07	2024	0.09	0.09	2031	0.09	0.07
2018	0.06	0.10	2025	0.08	0.09	2032	0.09	0.06
2019	0.07	0.10	2026	0.09	0.09	2033	0.08	0.05
2020	0.08	0.10	2027	0.09	0.08	2034	0.08	0.04
2021	0.08	0.10	2028	0.09	0.08	2035	0.07	0.02
2022	0.09	0.10	2029	0.09	0.08	2036	0.07	0.01

Source: Author's calculations

Comparing Table 6-7's Ft_boom values with Table 6-6's Ft_sum values shows a stark cushioning on the increase of the Ft over time. In the medium case of Table 6-7, the Ft value starts do decrease after 2031, after 2022 for a boom respectively. This is due to the decrease in costs for solar power, the learning effect. In those two years, the LCOE of the non-renewable power plant starts to be higher than the weighted average of installed new power of the three FiT rates. This means that the cost of the solar panels and the installing costs thereof are lower than the savings of reducing electricity production with the non-renewable power source. This result compares to other findings by a report by Bloomberg New Energy Finance (2017), they also predict that solar will be cheaper than coal or gas powered power plants in the 2020s. The initial increase in costs is larger for the boom scenario, since the end-consumer pays more electricity production from solar than in the medium case. However, because of the more rapid capacity increase, the costs for new solar electric energy decreases faster, and after 2025 the boom scenario is actually experiencing lower Ft values in the boom versus the medium solar installation increase scenarios. Therefore, we can say that increasing solar PV capacity will have costs in the beginning, but in later periods, the investment will reduce costs of new installations up to a point where it will be cheaper to only install solar PVs. However, for this to actually happen, the electricity grid needs to be able to handle different load generation in a decentralized electricity system or to be able to store excess energy in potential, thermal, residential and other storage types (Masters, 2004).

Table 6-8: Discounted Ft payments with learning, Ft in US cents/kWh.

Year	Ft_med	Ft_boom	Year	Ft_med	Ft_boom	Year	Ft_med	Ft_boom
2016	0.25	0.44	2023	0.03	-0.03	2030	0.02	-0.01
2017	0.13	0.19	2024	0.02	-0.05	2031	0.02	-0.02
2018	0.20	0.28	2025	0.00	0.00	2032	-0.01	-0.06
2019	0.13	0.09	2026	0.04	0.01	2033	-0.02	-0.11
2020	0.06	0.02	2027	0.01	0.00	2034	-0.02	-0.11
2021	0.04	-0.01	2028	0.03	0.00	2035	-0.03	-0.12
2022	0.08	0.06	2029	0.03	-0.01	2036	-0.03	-0.13

Source: Author's calculations

In Table 6-8, each year depicts the discounted Ft over the supported 25-year period. The first couple of years are the most expensive. Those high costs have two causes, because of the faster increase of new installations up to 2020 compared to the later years and because the learning effects do not yet as well. However, in the boom case, the NPV of the subsidy and the savings already almost offset each other by then. In that scenario, after 2028, solar PV installations on a per kWh basis would strictly be cheaper than the non-renewables used in this study, while this does not happen in the medium case up to 2036. The FiT for residential rooftop installations is 66.29USD/MWh in 2036, while old clean coal technology LCOE is lower at 60.58UD/MWh. In the boom scenario, solar PV FiT are in a range from 40.99-49.61USD/MWh, while old clean coal technology hovers above 60USD/MWh. The decreasing subsidy achievements in the later years in the boom scenario do not offset the previous costs in the first couple of years of the FiT program tough. The first seven years have an accumulated Ft of over one US cent/kWh, whereas the last seven years accumulate to -0.57 US cent/kWh, which is about have of the initial costs. Using the Ft_boom values and discounting them will diminish the later year cost savings. Therefore, whichever scenario we look at, implementing solar power in Thailand comes at a cost, however, over time these cost turn to savings. Over the very long term, those costs may pay off in lower cost of electric energy and cleaner air.

Sensitivity analysis

The sensitivity analysis does not reveal different results relatively. A lower solar capacity factor or a replacement of the FiT by the overall lower solar LCOE lead to overall lower subsidies, as less solar energy is produced, respectively lower subsidy values paid out. Changes in the learning rates for solar, does have the expected opposite effects on the subsidy, higher or lower costs, depending on what direction the learning rate change was. Learning rate changes in the other power plant technologies does not experience significant changes. A change in the discount rate has no effect on the Ft value that pays the subsidy on a yearly basis, but it does on the NPV Ft values. A lower discount rate experiences are more positive Ft values in the beginning and more negative in the later years. The lower discount rate just amplifies the absolute value of the Ft.

Table 6-9: Discounted Ft payments without learning, discount rate at 5%, Ft in US cents/kWh.

Year	Ft_med	Ft_boom	Year	Ft_med	Ft_boom
2015	0.00	0.00	2026	0.41	0.81
2016	0.50	1.01	2027	0.08	0.16
2017	0.36	0.72	2028	0.30	0.60
2018	0.59	1.17	2029	0.34	0.67
2019	0.70	1.40	2030	0.35	0.70
2020	0.38	0.76	2031	0.35	0.70
2021	0.38	0.76	2032	0.23	0.45
2022	0.42	0.85	2033	0.32	0.63
2023	0.35	0.71	2034	0.33	0.65
2024	0.36	0.72	2035	0.34	0.68
2025	-0.02	-0.04	2036	0.38	0.76

Source: Author’s calculations

Table 6-10: Discounted Ft payments with learning, discount rate at 5%, Ft in US cents/kWh.

Year	Ft_coal	Ft_med	Ft_boom	Year	Ft_coal	Ft_med	Ft_boom
2015	0.00	0.00	0.00	2026	-0.13	0.07	0.02
2016	-0.31	0.39	0.69	2027	-0.07	0.01	0.00
2017	-0.50	0.19	0.29	2028	-0.04	0.04	0.00
2018	-0.13	0.30	0.44	2029	-0.07	0.04	-0.01
2019	-0.17	0.21	0.14	2030	-0.07	0.04	-0.02
2020	-0.16	0.09	0.04	2031	-0.06	0.03	-0.03
2021	-0.12	0.07	-0.01	2032	-0.07	-0.01	-0.10
2022	-0.12	0.12	0.10	2033	-0.07	-0.03	-0.16
2023	-0.10	0.04	-0.04	2034	-0.09	-0.03	-0.17
2024	-0.14	0.02	-0.09	2035	-0.10	-0.04	-0.18
2025	-0.17	0.00	0.00	2036	-0.12	-0.05	-0.20

Source: Author's calculations

6.6 Conclusion

This section calculates the costs of the solar FiT, a solar PV subsidy, in Thailand for the PDP2015, netting the actual costs of the solar subsidy and the savings of lower non-renewable energy production. The results show that incentivizing solar comes at a cost, large costs if there are no instruments in place that counter increasing subsidy costs. In Thailand, there is a limit on the maximum new solar PV installations that can be added to the grid under the solar FiT. Two scenarios of higher and one of lower solar PV capacities are compared versus the BAU case that is depicted in the PDP2015.The coal scenario that installs clean coal instead of solar power is cheaper than the BAU case, since there is no subsidy paid out and a cheaper power technology added. The other two scenarios, a medium and boom scenario there is a learning and a no learning case studied. The learning case assumes that FiT rates decrease each year for newly installed capacity. These results are then again divided up into Ft values that either represent the steadily increasing costs of the subsidy paid only in the year it occurs, or in a discounted fashion where the total subsidy costs for new solar PV installations are assumed in the year the solar PV is added to the grid. The second approach does not hide the net-subsidy costs, while the former representation does not show the full scale of the costs, since we do not include the subsidies paid out after 2036.

Implementing the BAU scenario in Thailand is a sensible decision when considering costs to end-users. All of the considered scenarios have positive subsidy costs over the time frame considered. PV technology is not yet a cheap option, however, this may change in the next couple of years through the high learning rate the technology is experiencing. In the no learning cases, the cost increases can be substantial, with yearly discounted costs of over 0.40 US cent/kWh in each year and accruing Ft prices up to 0.84 US cent/kWh in 2036; about have for the medium cases respectively. The learning cases are more interesting, since lowering FiT rates based on LCOE could replace the limit on new solar PV installations and still keep the total subsidy amount in check. When the Ft is accrued yearly then the subsidy is first increasing up to the point where the learning effect of more installed solar capacity has rendered the solar FiT rates lower than the non-renewables' LCOE considered, which are old and new clean coal and gas power. Then, the Ft starts to slowly decrease, towards the end of the time frame considered, in the boom case, the Ft is almost back to 0 US cent/kWh again, 7 US cent/kWh in the medium case respectively. Discounting for the whole supporting period of 25 years for each year's Ft, reveals the true net-subsidy costs. First these costs are high positive values, that decrease sharply due to the rapid decreasing FiT rates, especially in the boom scenario. This is because of the low total solar capacity values in 2015 for each FiT type. After some point, the discounted net-subsidies turn negative as a result of lower solar FiT rates against the non-renewables' LCOE. Thus, the solar PV subsidy program could be restructured, with minimal additional costs, but large solar PV generating capacity increases. In order to achieve this, the policy maker should suspend the limit on solar PV additions per year and replace this cost restraining method with a lower FiT that also decreases over time according to the decreasing market costs of solar PV. Furthermore, the intermediate results on where the solar PV price is heading in the next years is quite interesting. Solar PV may be cheaper during the 2020's, however, some learning-by-doing by adding capacity needs to happen along the way.

This section studies the solar FiT, however, in Thailand, there is also an adder program for other renewables in place. A further study may use scenarios of various mixes of renewable technologies to calculate the subsidy costs of the adder program as well. This would be interesting in the case of wind and biomass, as the policy maker schedules to increase the 2015 accumulated capacity of those two technologies over 13-fold to 3,002MW by 2036 for wind, and a bit more than doubling of the installed capacity to 5,570MW for biomass respectively. Furthermore, there may be a change in the subsidy to include solar and wind together, as these two technologies deliver electricity at oppositional times to each other.

Section 7

7 Conclusion

7.1 Main findings and policy implications

In this thesis, I have related the proposed Thai clean coal projects to possible structural economic changes in southern Thailand, to the costs of other power plant technologies, and to the solar subsidy.

The clean coal projects that EGAT proposes to build in southern Thailand will have some effect on the local economy, but more research needs to be put in, in order to study the ripple effects over time. This would make the extent of the impact more apparent and would help the policy makers in those provinces to plan for possible future needs of infrastructure, respectively the central government in Bangkok.

The costs of the clean coal projects are reasonably low, and a coal power plant can provide a stable energy supply. Albeit, the power plant is relatively dirty in its pollution, the choice to build some base power plants in southern Thailand is justifiable. Thailand's grid may not yet be able to integrate gigawatt of dispersed solar or wind power, a first step may be to incentivize smart meter installments in homes and business in order to be able to implement net metering. The levelized costs for energy in Thailand should be determined every other year. Solar energy cost is decreasing every year and in the next 15 years, may already be competitive with clean coal. It does not have the fuel cost risks and there are no carbon emissions, however, there are production emissions and what will be done with the solar panels after their lifetime needs to be figured out.

The solar subsidy is an effective way to boost the installments of solar power. There needs to be a subsidy, since the levelized costs of solar power is still higher than clean coal. A subsidy scheme that does not decrease the subsidy amount with lower levelized cost is expensive over time. Consequently, there is a cap on the subsidy, that limits the amount of generating capacity installed. Yet, this is counterproductive, if expanding the solar installments is the objective. It would be better to loosen the ceiling on new yearly installments and to implement some sort of learning formula that decreases the subsidy rate per energy produced over time, in line with the decreasing rate of the levelized costs, that includes cheaper financing possibilities in the maturing solar market.

All in all, the energy policy maker adjusts its power development plan over time and they should account for the changes in the market environment for fuels, the social acceptance of certain power plant technologies, and rapidly decreasing levelized costs of some renewables. The solar FiT should be adjusted over time, when new information on levelized costs for solar power is available and may integrate lower subsidy values per energy unit over time but keeping the total additional subsidy amount per year stable, this would increase total solar generating capacity.

7.2 Contributions of the study

This study contributed to the literature in creating new data, methods, formulas, and in calculated results for policy recommendations.

The first study developed a method to regionalize the national Thai IO table for southern Thailand for 2015, as well as the national German IO table for Brandenburg in 2011. That method was used to then produce those two tables. Furthermore, the study has forecasted how the clean coal power plants may impact the regional economy by calculating the regional demand growth of those plants.

The second study has formed an accumulation of characteristics, costs, and carbon emissions for over a dozen power plant technologies. Furthermore, LCOE were then calculated for Thailand. Also, possible carbon mitigation costs over clean coal power plants have been calculated in form of hypothetical carbon certificate prices that would set the energy producer indifferent between the clean coal and other power producing technologies.

Lastly, the third study developed a new formula where the subsidy costs of the Thai solar FiT are reduced by the energy production costs of the replaced technology. Detailed data on power and energy production additions per year from 2015-2036 are calculated and made available online. Additionally, LCOE and FiT rates per year conditional on its total installed capacity over the 2015-2036 timespan have been estimated. Moreover, the future Ft prices for the solar subsidy in different scenarios using the adjusted formula are calculated.

7.3 Limitations and future research

The studies face some limitations. The first study does not include the indirect effects on the local economy, the IO table depicts the regional economy for a year that it has completed transformation. In future research, a dynamic computable general equilibrium model would be able to estimate the effects over time. Furthermore, a paper by Dai and Yang (2013) uses a simple multiplication model for different factors to transform the IO values into indirect effects. Moreover, no assessment on the impact on the regional tourism sector can be made. The study covers the inputs into the electricity sector. However, in order to estimate the impact of the power plant on the tourism sector, the tourism sector column would need to be analyzed, as well as pollution and health impacts assessed. This study also excludes pollution, due to the non-regional nature of, mostly, air pollution. However, carbon emissions are considered in the second study. The main limitation in the study for LCOE in Thailand is the lack of data on local renewable costs. Therefore, future research on the costs of renewables in Thailand from Thai firms would further the insights on how much the levelized costs of solar or wind actually is. The third study's limitations are probably the long timeframe of over 20 years. There may be new renewable technologies emerging in this time that will produce electricity cheaper and cleaner, or solar power will get so cheap and Thailand's grid, especially on the consumer side with net-metering, will get smart. Then, at some point when solar energy will become cheaper than the energy produced by large base load power plants. The end-user of electricity may just want to install rooftop solar unilaterally, without receiving a subsidy. Hence, there may be a boom scenario that is not entirely driven by the solar subsidy. Therefore, it would be interesting to get more exact levelized costs of solar, as just mentioned above. Then new scenarios that take unsubsidized solar installations into account would make future cost increases for the consumer more exact.

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APPENDIX

Table 0-1: Study 1 - Price level adjustments for each sector.

Sector number	Sector description	Sector inflation	Sector number	Sector description	Sector inflation
1	Agriculture, Hunting and services thereof	101.71	23	Other Manufactured Products	108.90
2	Forestry and services thereof	101.71	24	Electricity	106.77
3	Fishery	128.75	25	Gas, Pipe Line (LPG, natural gasoline NGL)	106.77
4	Coal and Lignite	110.34	26	Water Works and Supply	106.77
5	Petroleum and Natural Gas (Drilling, Exploration)	110.34	27	Building Construction and Public Works	106.77
6	Metal and Non-Metal Ore	112.38	28	Trade, Repair	106.30
7	Food Manufacturing, Animal Food, Beverages and Tabacco Products	109.98	29	Transportation Land	96.28
8	Textile Industry	107.32	30	Tranportation Water	96.28
9	Saw Mills and Wood Products	104.50	31	Transportation Air	96.28
10	Paper, Paper Products and Printing	103.55	32	Silo and Warehouse and other Services	96.28
11	Petroleum Refineries	97.00	33	Post and Telecom	96.28
12	Chemical and Pharma Products	102.41	34	Restaurants and Hotels	102.55
13	Rubber Products	80.98	35	Banking Services	106.30
14	Glass Products	102.75	36	Insurance Services	106.30
15	Cement and Concrete Products, Ceramic Wares	102.75	37	Real Estate Services	106.30
16	Iron and Steel	98.41	38	Business Service	106.30
17	Non-ferrous Metal	98.41	39	Public Administration	106.30
18	Fabricated Metal Products	98.41	40	Eductaion	102.55
19	Industrial Machinery	105.11	41	Hospital	103.98
20	Electrical Machinery	97.38	42	Entertainment	102.55
21	Motor Vehicles an Repairing	105.20	43	Personal Services	106.30
22	Other Transportation	105.20	-	-	-

Source: Author’s calculations

Table 0-2: Study 1 - The LQ for each sector for both countries' IO tables.

Sector number	Sector description	LQ Branden-burg	LQ southern Thailand	Sector number	Sector description	LQ Branden-burg	LQ southern Thailand
1	Agriculture, Hunting and services thereof	1.00	1.00	23	Other Manufactured Products	0.93	0.72
2	Forestry and services thereof	1.00	1.00	24	Electricity	0.93	0.72
3	Fishery	1.00	1.00	25	Gas, Pipe Line (LPG, natural gasoline NGL)	1.00	0.95
4	Coal and Lignite	0.93	0.72	26	Water Works and Supply	1.00	0.95
5	Petroleum and Natural Gas (Drilling, Exploration)	0.93	0.72	27	Building Construction and Public Works	1.00	0.95
6	Metal and Non-Metal Ore	0.93	0.72	28	Trade, Repair	0.96	0.87
7	Food Manufacturing, Animal Food, Beverages and Tabacco Products	0.93	0.72	29	Transportation Land	0.96	0.87
8	Textile Industry	0.93	0.44	30	Tranportation Water	0.96	0.87
9	Saw Mills and Wood Products	0.93	0.44	31	Transportation Air	0.96	0.87
10	Paper, Paper Products and Printing	0.93	0.44	32	Silo and Warehouse and other Services	0.96	0.87
11	Petroleum Refineries	0.93	0.72	33	Post and Telecom	0.96	0.87
12	Chemical and Pharma Products	0.93	0.82	34	Restaurants and Hotels	0.96	0.87
13	Rubber Products	0.93	0.44	35	Banking Services	0.92	0.74
14	Glass Products	0.93	0.44	36	Insurance Services	0.92	0.74
15	Cement and Concrete Products, Ceramic Wares	0.93	0.44	37	Real Estate Services	0.92	0.74
16	Iron and Steel	0.93	0.72	38	Business Service	0.92	0.74
17	Non-ferrous Metal	0.93	0.72	39	Public Administration	1.00	0.74
18	Fabricated Metal Products	0.93	0.72	40	Eductaion	1.00	0.74
19	Industrial Machinery	0.93	0.72	41	Hospital	1.00	0.74
20	Electrical Machinery	0.93	0.72	42	Entertainment	1.00	1.00
21	Motor Vehicles an Repairing	0.93	0.72	43	Personal Services	1.00	1.00
22	Other Transportation	0.93	0.72	-	-	-	-

Source: Author's calculations

Table 0-3: Study 1 - Full results of inputs coefficients into the electricity sector, part 1 of 2.

Sector number	Sector description	BAU	All replaced for new technology	Krabi replaced, 800MW added	Krabi replaced, 1,800MW added	Krabi replaced, 2,800MW added
1	Agriculture, Hunting and services thereof	0.0007	0.0000	0.0005	0.0004	0.0003
2	Forestry and services thereof	0.0009	0.0000	0.0007	0.0005	0.0004
3	Fishery	0.0000	0.0000	0.0000	0.0000	0.0000
4	Coal and Lignite	0.0000	0.0000	0.0000	0.0000	0.0000
5	Petroleum and Natural Gas (Drilling, Exploration)	0.1835	0.0000	0.1318	0.0974	0.0773
6	Metal and Non-Metal Ore	0.0001	0.0004	0.0002	0.0003	0.0003
7	Food Manufacturing, Animal Food, Beverages and Tabacco Products	0.0019	0.0002	0.0015	0.0011	0.0009
8	Textile Industry	0.0002	0.0000	0.0002	0.0001	0.0001
9	Saw Mills and Wood Products	0.0001	0.0009	0.0003	0.0005	0.0006
10	Paper, Paper Products and Printing	0.0010	0.0009	0.0010	0.0010	0.0009
11	Petroleum Refineries	0.0000	0.0000	0.0000	0.0000	0.0000
12	Chemical and Pharma Products	0.0055	0.0010	0.0042	0.0034	0.0029
13	Rubber Products	0.0004	0.0001	0.0003	0.0002	0.0002
14	Glass Products	0.0000	0.0000	0.0000	0.0000	0.0000
15	Cement and Concrete Products, Ceramic Wares	0.0000	0.0000	0.0000	0.0000	0.0000
16	Iron and Steel	0.0000	0.0000	0.0000	0.0000	0.0000
17	Non-ferrous Metal	0.0000	0.0037	0.0010	0.0017	0.0021
18	Fabricated Metal Products	0.0016	0.0001	0.0012	0.0009	0.0007
19	Industrial Machinery	0.0129	0.0118	0.0126	0.0124	0.0122
20	Electrical Machinery	0.0369	0.0869	0.0510	0.0604	0.0659
21	Motor Vehicles an Repairing	0.0019	0.0009	0.0016	0.0014	0.0013
22	Other Transportation	0.0000	0.0000	0.0000	0.0000	0.0000

Source: Author’s calculations

Table 0-4: Study 1 - Full results of inputs coefficients into the electricity sector, part 2 of 2.

Sector number	Sector description	BAU	All replaced for new technology	Krabi replaced, 800MW added	Krabi replaced, 1,800MW added	Krabi replaced, 2,800MW added
23	Other Manufactured Products	0.0008	0.0000	0.0006	0.0004	0.0003
24	Electricity	0.0716	0.5295	0.2007	0.2864	0.3367
25	Gas, Pipe Line (LPG, natural gasoline NGL)	0.5109	0.0000	0.3668	0.2712	0.2151
26	Water Works and Supply	0.0005	0.0034	0.0013	0.0019	0.0022
27	Building Construction and Public Works	0.0024	0.0459	0.0147	0.0228	0.0276
28	Trade, Repair	0.0006	0.1144	0.0327	0.0540	0.0665
29	Transportation Land	0.0047	0.0206	0.0092	0.0122	0.0139
30	Tranportation Water	0.0000	0.0000	0.0000	0.0000	0.0000
31	Transportation Air	0.0022	0.0000	0.0016	0.0012	0.0010
32	Silo and Warehouse and other Services	0.0001	0.0024	0.0007	0.0012	0.0014
33	Post and Telecom	0.0052	0.0003	0.0038	0.0029	0.0023
34	Restaurants and Hotels	0.0144	0.0150	0.0146	0.0147	0.0148
35	Banking Services	0.1171	0.0191	0.0894	0.0711	0.0603
36	Insurance Services	0.0077	0.0178	0.0105	0.0124	0.0135
37	Real Estate Services	0.0004	0.0199	0.0059	0.0095	0.0117
38	Business Service	0.0104	0.0992	0.0354	0.0520	0.0618
39	Public Administration	0.0000	0.0000	0.0000	0.0000	0.0000
40	Eductaion	0.0008	0.0008	0.0008	0.0008	0.0008
41	Hospital	0.0000	0.0000	0.0000	0.0000	0.0000
42	Entertainment	0.0014	0.0000	0.0010	0.0007	0.0006
43	Personal Services	0.0010	0.0050	0.0021	0.0029	0.0033

Source: Author's calculations

Table 0-5: Study 1 - Full results of local inputs values into the electricity sector, in USD, part 1 of 2.

Sector number	Sector description	800MW Krabi Clean Coal Plant	1,000MW Thepa Unit 1 Clean Coal Plant	1,000MW Thepa Unit 1 Clean Coal Plant
1	Agriculture, Hunting and services thereof	-	-	-
2	Forestry and services thereof	-	-	-
3	Fishery	-	-	-
4	Coal and Lignite	-	-	-
5	Petroleum and Natural Gas (Drilling, Exploration)	-	-	-
6	Metal and Non-Metal Ore	696,046	1,566,105	2,436,163
7	Food Manufacturing, Animal Food, Beverages and Tabacco Products	327,551	736,990	1,146,429
8	Textile Industry	-	-	-
9	Saw Mills and Wood Products	1,392,093	3,132,209	4,872,325
10	Paper, Paper Products and Printing	1,392,093	3,132,209	4,872,325
11	Petroleum Refineries	-	-	-
12	Chemical and Pharma Products	1,596,812	3,592,828	5,588,844
13	Rubber Products	81,888	184,248	286,607
14	Glass Products	-	-	-
15	Cement and Concrete Products, Ceramic Wares	-	-	-
16	Iron and Steel	-	-	-
17	Non-ferrous Metal	5,854,979	13,173,703	20,492,426
18	Fabricated Metal Products	163,776	368,495	573,215
19	Industrial Machinery	18,875,142	42,469,070	66,062,997
20	Electrical Machinery	139,250,234	313,313,027	487,375,820
21	Motor Vehicles an Repairing	1,473,981	3,316,457	5,158,933
22	Other Transportation	-	-	-

Source: Author’s calculations

Table 0-6: Study 1 - Full results of local inputs values into the electricity sector, in USD, part 2 of 2.

Sector number	Sector description	800MW Krabi Clean Coal Plant	1,000MW Thepa Unit 1 Clean Coal Plant	1,000MW Thepa Unit 1 Clean Coal Plant
23	Other Manufactured Products	-	-	-
24	Electricity	848,194,018	1,908,436,540	2,968,679,062
25	Gas, Pipe Line (LPG, natural gasoline NGL)	-	-	-
26	Water Works and Supply	5,437,226	12,233,759	19,030,291
27	Building Construction and Public Works	73,601,475	165,603,319	257,605,163
28	Trade, Repair	183,190,287	412,178,146	641,166,005
29	Transportation Land	33,063,613	74,393,129	115,722,645
30	Tranportation Water	-	-	-
31	Transportation Air	42,553	95,744	148,935
32	Silo and Warehouse and other Services	3,829,762	8,616,965	13,404,167
33	Post and Telecom	468,082	1,053,185	1,638,287
34	Restaurants and Hotels	24,084,948	54,191,134	84,297,319
35	Banking Services	30,527,840	68,687,640	106,847,439
36	Insurance Services	28,443,610	63,998,122	99,552,634
37	Real Estate Services	31,835,592	71,630,082	111,424,572
38	Business Service	158,851,022	357,414,799	555,978,577
39	Public Administration	-	-	-
40	Eductaion	1,237,743	2,784,921	4,332,099
41	Hospital	-	-	-
42	Entertainment	-	-	-
43	Personal Services	8,001,121	18,002,523	28,003,925
-	Total	1,601,913,487	3,604,305,346	5,606,697,205

Source: Author's calculations

Code for study 1 - R code to calculate the sensitivity analysis for a well-conditioned matrix.

```
# Import data

mydata <- read.csv("/path/to/file/file_name.csv", nrows=43, header=FALSE, sep=",")

# Transform the data to a matrix

A <- as.matrix(mydata)

B <- diag(43) - A

H <- t(B) %*% B

# Get the eigenvalues lamda, select largest and smallest

lamdan <- max(Re(eigen(H)$values[abs(Im(eigen(H)$values)) < 1e-8]))

lamda1 <- min(Re(eigen(H)$values[abs(Im(eigen(H)$values)) < 1e-8]))

# Get the positive singular values of those eigenvalues

sigman <- sqrt(lamdan)

sigma1 <- sqrt(lamda1)

# Get kappa from these positive singular values

kappa <- (sigman / sigma1)

# Calculate tau by taking the reciprocal

tau <- 1/kappa

# Print the tau value

tau
```

Source: Wolff (2005)

VITA

Mister Christoph Casimir Odermatt was born on 16 August, 1985, in St. Gallen, Switzerland. He obtained his Bachelor and Master of Economics from the University of Bern, Switzerland, in 2010 and 2012, respectively. He started a Ph.D. at Korea University, Republic of Korea, but then move to do his Ph.D. at Chulalongkorn University, Thailand. He has published papers in the Journal of Southeast Asian Economies, titled 'Book review on ASEAN Economic Community: A Model for Asia-wide Regional Integration?', and the Journal of Virus Eradication, titled 'HIV-associated cognitive performance and psychomotor impairment in a Thai cohort on long-term cART'. His paper titled 'Clean coal project: Carbon certificate pricing', which is part of this thesis is going to be published in the International Journal of Trade and Global Markets (IJTGM).