The Impact of Regional Power Trade on CO₂ Emissions in the Greater Mekong Sub-region

Qinggui Chen¹, Bangcan Wang², Wenjiao Ding³, Zhengkan Liao⁴, Hong Zhang⁵ and Guixin Zhao⁶

¹ Kunming Power Exchange Center Company Limited, Kunming, China
² North China Electric Power University, Beijing, China
³ ding_fighting@outlook.com
⁴ 873810600@qq.com; ² 278792706@qq.com; ³ 379780355@qq.com

Abstract: The Greater Mekong Sub-region (GMS) is a natural economic area bound together by the Mekong River, and the GMS member countries includes Cambodia, the People's Republic of China (PRC, Yunnan Province and Guangxi Zhuang Autonomous Region), Lao People's Democratic Republic (Lao PDR), Myanmar, Thailand, and Viet Nam. In recent years, with the economic growth of the Greater Mekong Sub-region countries, the demand for electricity has been growing rapidly, and that might lead larger CO₂ emissions. Fortunately, there are abundant hydroelectric power resources in this region, and huge potential for complementarity in the supply and demand of electricity among countries. In this paper, an economic optimal dispatching model for thermal and hydroelectric generating units is introduced, and the effects of interconnections and cross-border power trade on the CO₂ emissions in the Greater Mekong Sub-region are investigated. Finally, through a concrete example, it can be proved that after the implementation of interconnection and cross-border electricity trade in the Greater Mekong Sub-region, the CO₂ emissions will be greatly reduced.

1. Introduction
The Greater Mekong Sub-region (GMS) is a natural economic area bound together by the Mekong River. In the last two decades, the GMS member countries are undergoing rapid social and economic development, which has led to increasing demand for energy and electric power. Under the Belt and Road Initiative, the GMS member countries are seeking advance comprehensive collaboration on power exploration and trade, energy infrastructure construction. However, the economic development and energy status of the GMS member countries are quite different. PRC (Yunnan and Guangxi), Thailand, and Vietnam are experiencing rapid economic growth, and the power consumption growth is much higher than supply, which led to a strong demand for energy imports. Although Myanmar, Lao PDR and Cambodia are rich in energy, due to the poor power infrastructure, they cannot even meet their domestic power demand.

At the same time, this region also has to face the greenhouse gas emission and climate change issues. Greenhouse gas concentrations will continue to increase Earth's average temperature, influence the patterns and amounts of precipitation and many other effects. For instance, the global average temperature has risen 1.6°F (0.9°C) over the past 140 years, and half of that changes in global average temperature took place in the past three decades [1]. Carbon dioxide (CO₂) is the primary greenhouse gas emitted through human activities, while the main human activity that emits CO₂ is the
consumption of fossil fuels (coal, oil, gas) for energy. Currently, the Southeast Asian countries heavily rely on conventional energy sources [2], that leads to the fact the majority of coal-fired electricity generation is found in Asia nowadays. Therefore, the most effective way to cut down the global CO₂ emissions is to replace the coal-fired electricity generation in Asia area.

Today, renewable energy is widely recognized as a tool for reducing greenhouse gas emissions. Moreover, the Greater Mekong Sub-region is abundant in water resources and other renewable energy, and the region is undergoing extensive hydropower development. Besides, the power generation mixes in GMS member countries are quite diversified, fossil energy and wind energy is mainly concentrated in Vietnam; PRC (Yunnan), Myanmar and Lao PDR are countries with rich water resources; solar energy resources are relatively abundant in the Thailand. Therefore, there are great opportunities for the GMS member countries to complement in power demand and supply through cross-border power trade. In addition to optimal allocation of power resources and lower average electricity prices, the interconnections and cross-border trade would also optimize the use of hydropower resulting in reduced greenhouse gas emissions in the GMS as a whole.

There are many experiences in world for interconnection and cross-border power trade, and the Internal Electricity Market (IEM) in Europe is a good example for the GMS area. Over the past two decades, addressing the double challenges of climate change and energy security, the European energy markets has been going through a reform moving to a single integrated market. In order to cope with the climate change, European countries continue to carry out renewable energy policies for low carbon development, and many transmissions have been built to interconnect power systems between neighborhood countries to achieve the renewable energy integration target. At the same time, the European Union is pushing forward the IEM, which tries to remove the obstacles of cross-border electricity trade among EU countries, and promotes the free transaction and efficient integration of renewable energy in a wider range of Europe [3-5].

Interconnection and cross-board power trade will reduce system backup requirements, reduce the peak load of the entire system at the same time, hence it would help to improve the efficiency [6]. Power grids interconnections can expand the power supply boundary, and may contribute a lot to the power system as well as the market participants. First, interconnections can lead to improved energy efficiency and energy reliability. Besides the benefits from general commodity trade, the reliability improvement is an exclusive external benefit of electricity trade. Second, interconnections can increase level of competition significantly within the market because of the electricity import, and then they can help increase the market efficiency, reduce the cost of power supply, and finally leads to increase of producer and consumer surplus. Third, considering the generation mix in areas within the system could be quite complementary, so it also helps renewable energy integration, reduce the renewable generation curtailments, and bring about lower CO₂ emissions. For China in particular, in 2017 the coal plants have an average emission intensity of 844 tons of CO₂ per GWh [7]. In the same year, the cross-regional/provincial clean energy transaction amounted to 587000 GWh according to the government statistics. Therefore, the clean energy transaction cut down the CO₂ emissions approaching 500 million tons per year.

However, Charpentier and Schenk (1995) believe that there is no complete “trade” of electricity, the market segmentation and transportation costs or border taxes has a great inhibitory effect on the cross-board power transaction. Mutual trust and mutual benefit in politics and economy are the central premises to build power grid interconnections, which are different from domestic market transactions, hence complex organizations and coordination are needed [8].

For the GMS area empirical research, Zhai and Jude (2013) shows that the sub-regional integration helps the countries achieve the target of low carbon development, and suggests that GMS cooperation provides an effective international lesson to cope with climate change [9]. Watcharejothin and Shrestha (2009) introduces an integrated energy system model of the GMS countries to examine the benefits of cross-border power trade, and finds that trade within the region will reduce the total carbon dioxide emissions by 5%, and all the countries but one would benefit from the interconnection [10]. Tian Wei (2016) studies the electric power markets in Southeast Asian, and proposes the
implementation guidelines for electric power cooperation in this area, including the investment opportunities in renewable energy [11]. For a single country study, Middleton C. (2012) analyses the environmental and social costs of domestic and imported power projects for Thailand, and suggests that Thailand exploits the fragility of neighboring countries and gain economic and environmental benefits from power trade [12].

2. Model Specifications
In this paper, the optimal dispatching problem for thermal-hydro units with cross-border interconnections in the GMS region is discussed. The power generation mixes of the target countries show that thermal and hydroelectric power units are the majority of all the power sources in the GMS countries, if we assume that other types of power generation in this model are negligible, then the power loads in the target regions are totally balanced by thermal and hydroelectric power units in this paper. Total generation for GMS member countries is as shown in the following Figure 1 and the installed generation mix in 2016 is as shown in Figure 2.

![Figure 1. Total generation for GMS member countries.](image1)

![Figure 2. The installed generation mix in 2016.](image2)

In the operation of power system, because of the flow uncertainty, there are much more restrictions for hydropower plants, and the optimal dispatching problem for hydropower and thermal power systems would be more complicated than that of full thermal power systems. The objective of hydro-thermal joint dispatch optimization is to minimize the operation cost of the power system under given demand level and water volume constraints. However, the operation cost for hydropower plants is negligible compared with thermal power plants, then the typical objective function for economic dispatch in hydropower and thermal power systems would be:

$$\min F = \min \sum_{k=1}^{N_G} \sum_{t=1}^{T} [a_k P_{G,k}(t) + b_k \phi_k(t)] + \sum_{t=1}^{T} \rho P_{IL}(t)$$

where $k$ is the index of thermal power plant (from 1 to $N_G$), $t$ represents the index of time periods (from 1 to $T$), $a_k$ and $b_k$ are the cost coefficient of the $k$th thermal power plant, $P_{G,k_{max}}$ and $P_{G,k_{min}}$ are the upper and lower limits of the power output of the $k$th thermal power plant, $P_{G,k}(t)$ stands the output of the $k$th thermal power plant in period $t$, $\rho$ stands the value of lost load and $P_{IL}(t)$ means the excision load in period $t$. $\phi_k(t)$ indexes the start-stop state of the $k$th thermal power plant in period $t$, $\phi_k(t)$ is 1 while the unit start-up; on the other hand, $\phi_k(t)$ is 0 while the unit shutdown. In a system with thermal and hydroelectric power units, the power supplied from the generations must satisfy the load demand $P_{Load}(t)$ in a certain period $t$, which is represented as:
At the same time, the output of each thermal or hydro power unit in a certain period has its generation range, which is represented as:

\[ P_{G_k \text{min}} \leq P_{G_k}(t) \leq P_{G_k \text{max}} \quad \forall k, \forall t \]  

(3)

Because the hydroelectric power generation has no contribution to the CO\(_2\) emissions, the CO\(_2\) emissions of the power system is the same to the thermal power units’ emission, and the latter is determined by the net load, which is the total electric demand in a certain period of the system minus hydroelectric power generation in the same period of time. The CO\(_2\) emissions of the power system come from thermal power units and their carbon emissions are influenced by fuel composition, fuel combustion efficiency, thermal efficiency and many other factors. In generally, a quadratic approximate model could be used to calculate the CO\(_2\) emission.

\[ EC_{k,t} = \alpha_k + \beta_k \times P_{G_k}(t) + \gamma_k \times P_{G_k}(t)^2 \]  

(4)

where \( EC_{k,t} \) is the CO\(_2\) emission of the \( k \)th thermal power plant in period \( t \), and \( \alpha_k, \beta_k, \gamma_k \) are the CO\(_2\) emission coefficient of the \( k \)th thermal power plant. In this paper, the four-unit system with standard input data of power plants and emission coefficients is used. The estimated power plant units data and emission coefficients are given in Table 1. The daily load curves are given in Figure 3 and Figure 4 for wet season and dry season respectively.

### Table 1. System Parameters Of four Units.

| Parameters   | Unit 1 | Unit 2 | Unit 3 | Unit 4 |
|--------------|--------|--------|--------|--------|
| PGmax(MW)    | 455    | 130    | 85     | 55     |
| PGmin(MW)    | 150    | 20     | 25     | 10     |
| \( \alpha \) (ton/h) | 10.33908 | 30.0391 | 33.00056 | 33.00056 |
| \( \beta \) (ton/MWh) | -0.24444 | -0.40695 | -0.39023 | -0.39023 |
| \( \gamma \) (ton/MW2h) | 0.00312 | 0.00509 | 0.00465 | 0.00465 |

**Figure 3.** Daily net load curve in wet season.  
**Figure 4.** Daily net load curve in dry season.

### 3. Results and Discussion

In this paper, the following two scenarios are investigated to show the effect power grids interconnections and cross-border power trades on the CO\(_2\) emissions in the Greater Mekong Sub-
region. The calculations are carried out for wet season and dry season for each scenario respectively. Finally, the results of two scenarios are compared and analyzed.

Scenario 1 (independent systems): for each country in this region as an independent power system, the typical daily CO\textsubscript{2} emissions of Vietnam, Laos, Myanmar, Thailand, Cambodia and Yunnan PRC are calculated under the established economic optimal dispatching model.

Scenario 2 (unified system): considering the whole regional as a unified power system, the daily CO\textsubscript{2} emission of the unified system is calculated under the established economic optimal dispatching model.

The results of the calculations are shown in Table 2. Since the hydroelectric power units can satisfy more power demand in the wet season, the daily CO\textsubscript{2} emissions are lower than the dry season.

**Table 2. Results of daily CO\textsubscript{2} emissions.**

| Scenario | Area      | Wet season | Dry season |
|----------|-----------|------------|------------|
| Scenario 1 (tons) | Vietnam | 154,434 | 159,293 |
|          | Laos     | 8,097     | 8778       |
|          | Cambodia | 9,651     | 10,163     |
|          | Thailand | 240,934   | 243,177    |
|          | Myanmar  | 6,145     | 6,802      |
|          | Yunnan, PRC | 43,000 | 79,052 |
|          | Total    | 462,262   | 507,265    |
| Scenario 2 (tons) | Total    | 398,496   | 463,474    |
| Reduction (%) |          | 13.79%    | 8.63%      |

Daily CO\textsubscript{2} emissions in different scenarios is as shown in Figure 5. The results show that with the cross-board interconnections, the CO\textsubscript{2} emissions for the whole region are 8.63-13.79% lower than the total emissions of each system without interconnection, which means there are tens of thousands of CO\textsubscript{2} emissions reduction within a single day. Hence, this investigation means that the interconnections between Greater Mekong Sub-region countries can achieve significant reduction in CO\textsubscript{2} emissions and contribute to cope with the global climate change problems.

![Figure 5. Daily CO\textsubscript{2} emissions in different scenarios.](image)
4. Conclusions
In enhancing the integration of the Greater Mekong Sub-region countries, cooperation within the energy sector will be helpful to face the energy challenges and environmental problems of the region. From the view of international experience in cross-border power markets, carrying out interconnections construction and cross-border power trade can improve the reliability, lower the cost of power supply, as well as reduce the CO₂ emissions in the region. This paper puts forward the idea of establishing the cross-border power market in the Greater Mekong Sub-region, and establishes an economic optimal dispatching model for hydro and thermal power units. The CO₂ emissions in different scenarios show the environmental benefits from the regional power market are impressive. However, there are many obstacles for the Greater Mekong Sub-region power market. For example, the difference understanding of legal system, religious and cultures may make it relatively harder to build mutual trusts in this region than Europe countries, and bring risks for the interconnections investment and power supply security. Hence, it would take a quite long time to establish the Greater Mekong Sub-region power market.

References
[1] IEA 2009 Statistics and balances (Paris: International Energy Agency)
[2] Erdiwansyah, Mamat R, Sani M S M. and Sudhakar K 2019 Renewable Energy in Southeast Asia: Policies and Recommendations J. Sci. Total Environ. 670 1095-1102
[3] D. Newbery, M G Pollitt, R A. Ritz, and W Strielkowski 2018 Market design for a high-renewables European electricity system J. Renewable and Sustainable Energy Reviews. 91 695-707
[4] L Meeus, K Purchala, and R Belmans 2005 Development of the Internal Electricity Market in Europe J. The Electricity Journal. 18 25-35
[5] L Morales and J Hanly 2018 European Power Markets–A journey Towards Efficiency J. Energy Policy. 116 78-85
[6] Georg Gebhardt and Felix Höffler 2013 How Competitive is Cross-border Trade of Electricity? Theory and Evidence from European Electricity Markets J. The Energy Journal. 34 125-154
[7] China Electricity Council 2018 China Electric Power Industry Annual Development Report 2018 (China Market Press) p 179
[8] Charpentier J P and Schenk K 1995 International Power Interconnections: Moving from Electricity Exchange to Competitive Trade (Washington, DC: Public Policy for the Private Sector, Would Bank, Industry and Energy Department) Note No. 42
[9] Zhai Y and Jude A 2013 Energy Sector Integration for Low-carbon Development in the GMS: Towards a Model of South-South Cooperation, Greater Mekong Sub-region: From Geographical to Socio-economic Integration J. Institute of Southeast Asian Studies 216-232
[10] Watcharejyothin M and Shrestha R M 2009 Regional energy resource development and energy security under CO₂ emission constraint in the greater Mekong sub-region countries (GMS) J. Energy Policy 37 4428-4441
[11] Tian Wei 2016 Preliminary Study of the Electric Power Markets in Eight Southeast Asian Countries J. Hydropower and New Energy 11 61-62
[12] Middleton C 2012 Transborder Environmental Justice in Regional Energy Trade in Mainland South-East Asia J. Austrian Journal of South-East Asian Studies, 5 292-315