MINISTRY OF EDUCATION & TRAINING

**HANOI UNIVERSITY**

# Apply game theory in modeling solutions to solve water conflict among countries in the Mekong River Basin by Non-dominated Sorting Genetic Algorithm-II (NSGA-II)

SS207 (Monday) - Group 2:
**Nguyen Tung Anh - 1901040014**
**Pham Chung Duc - 1901040014**
**Nguyen Minh Duc - 1901040014**
**Pham Thi Loan - 1901040014**
**Nguyen Duc Long - 1901040014**

Supervised by: **Dr. Trinh Bao Ngoc**

Faculty of Information Technology
Hanoi - 2022

# Contents

**Abstract**

There have been water tensions between countries in the Mekong basin area for a long time due to the fact that hydropower building and exploitation of water resources in many fields in upstream countries have had an impact on the condition and condition of water downstream. Clashes over water assets occur in a variety of industries, including agriculture, hydropower, fisheries, pollution, ecosystem diversity, navigation, ecotourism, and alluvium. Since its inception, game theory has been utilized to imagine social circumstances among competing players and aid participants in choosing optimal decisions in strategic situations. Therefore, using the game theory model, with each country in the Mekong River basin acting as a player with its strategy, the basin's countries then come to a settlement on the advantages of using water resources, which improve bilateral ties, decrease conflicts of interest, and ensure the long-term sustainability of water resources. Furthermore, by using the NSGA-II algorithm, leaders of countries identify suitable solutions to the water dispute in the Mekong River area. Lastly, our aim in the study is not only to figure out the specifically algorithmic method for six Mekong neighboring countries to effectively exploit the abundantly riparian water resources but also to contribute a new math formula in managing water conflicts among many other rivers on the planet.



*Keywords*: Game theory, Unified Game-Based Model, NSGA-II algorithm, water conflict, the Mekong River basin.

# 1 Introduction

The Mekong river is of paramount importance to a huge number of Southeast Asia's people living in the countries that it runs through, including China, Laos, Myanmar, Vietnam, Thailand, and Cambodia. It does not only supply abundant water resources but also affects a variety of areas like agriculture, hydro-power, ecotourism, and so on. However, it leads to many conflicts between upstream countries and downstream countries. Upstream countries' excessive water use and hydro-power construction endanger downstream countries' water quality and quantity. In addition, it also causes a slew of problems in many areas like the water supplement for agriculture, hydropower, the environment, and tourism. Osama Rahil Shaltami indicates several factors that affect water resources such as hydropower, overuse of water, and water conflict in some rivers in the world. These conflicts can lead to war among countries in the Mekong Basin. According to Pearse-Smith, a military clash, maybe a "water war" between upstream and downstream countries might happen because of the speedy expansion of hydropower that risks the cohesion of the river system.

Game theory assists players in analyzing circumstances and deciding interconnectedness. Because of this interconnectedness, each player must consider the other player's potential options, or tactics, when developing a plan. In this paper, essential progress in dealing with exploitation conflicts in this river system was made when applying game theory.

To handle multi-objective optimization problems, the NSGA-II method (Non-dominated sorting genetic algorithms) is utilized. It uses a special type of crossover and alternation to develop offspring. The next generation is then chosen using nondominated sorting and crowding distance comparisons. This paper demonstrated the effectiveness of a model for optimum water supplements allocation that takes intergenerational fairness into account, as well as the problem of water supply and demand. In addition, the Mekong River basin's upstream and downstream countries are determined using the NSGA-II formula to find the appropriate distribution of water supplements.

In general, all these publications describe the problems with water resources and measure the problem accurately based on the studied data. Furthermore, they also mention the main problems and give some answers to them. However, the problem is just figured out simply or several common aspects of water resource conflict are found out; in addition, there is not any mathematically based methodology that is applied to solve the problems. Therefore, our study will solve water resources problems by using a Unified game-based model among the six countries in the Mekong river basin. Addressing the current water problem is an exceptionally pressing issue for a nation or district and the whole world as the water source is progressively dirtied with the consistent change in the environment. Moreover, we will use Game theory as a way to observe the problem. Obviously, each of the particular issues that every nation faces is also the way and bearing to give every country an answer for making the most advantageous and safe.

By applying the game theory model and the NSGA-II algorithm in this paper, these basic problems will be profoundly analyzed to come up with reasonable strategies for resolving conflicting issues. A quick crowded-distance estimating process, a quick non-dominated sorting strategy, and a straightforward crowded comparison operator make up the three key components of the multi-objective optimization technique known as the NSGA-II. By applying this algorithm, the multi-objective optimization problem was clarified by mathematical formulas, and the countries in the Mekong River basin's water dispute can now be resolved.

The remainder of this essay is structured as follows: the literature study is covered in section 2, the problem description is introduced in section 3, and the Unified Game-Based Model for conflict is applied in section 4.

## 2 Literature Review

Water crossing boundaries has always been an issue of concern for many countries around the world because of its importance affecting many fields such as economy, politics, culture, etc (Priscolli, 2009) has clearly stated that water boundaries were considered to be a negotiation phase among nations in which their attempts were made to safeguard a vital resource as well as to preserve the natural environment. According to G.E.Petts (2013), the effective management of water from the upstream stream also greatly contributes to the provision of sufficient water volume and the prevention of flood intensity in the downstream area (Loucks, 2009) ascertained how significant water brings to our lives "We depend on our water resource systems for our survival and welfare". Therefore, intractable water conflicts are prone to become more frequent, more intense, and more disruptive all over the world if there are no strategies devised to anticipate and address these issues.

One of the world's incredible streams - the Mekong - is likewise one of the world's most geostrategic areas in which there exist conflicting tensions over water among regional states including Vietnam, Cambodia, Laos, Thailand, Myanmar, and China. According to Shaltami and Jay (2020), several reasons for the water conflict were pointed out including the unevenly distributed scarce natural freshwater resource used for irrigation and energy generation, which mostly impacts the economic conditions of a certain region. The unrestricted and devastating development of hydroelectric dam construction among unequal competition for freshwater resources could possibly pose a threat to the armed conflicts among nations (Shkara, 2018). Moreover, the opinion of Kittikhoun and Staubli (2018) indicated that the Mekong River Commission (MRC) was founded in 1995 with a purpose of cooperation for the development and upgrading of the Mekong River; nevertheless, its mission failed with the ineffective, uninfluential and wasted work. The refusal of China to turn into an individual from the MRC makes its activities upstream not limited by the MRC's guidelines and necessities; in addition, the little economic capacity has limited the downstream countries from investing in their regional programs. Minh Thu (2020), has demonstrated that "This form of cooperation makes them voiceless and powerless in asserting their own regional and national interests.". Hence, the rediscovery and reapplication of a new organized set of social, environmental, and economic relationships among countries is a necessarily continuous process to prevent and manage the conflict in the Mekong River bowl (Buxton, Martin &

Kelly) (2006).

This table shows one of the reasons making conflict between water resources in the Mekong river among the countries:

| No. | Country | Basin area ($km^2$) | Rate compared to whole basin (%) | Contribution of flow (%) |
|---|---|---|---|---|
| 1 | China | 165000 | 21 | 16 |
| 2 | Myanmar | 24000 | 3 | 2 |
| 3 | Laos | 202000 | 25 | 35 |
| 4 | Thailand | 184000 | 23 | 18 |
| 5 | Cambodia | 155000 | 20 | 18 |
| 6 | Vietnam | 65000 | 8 | 11 |
| | Total | 795000 | 100 | 100 |

Table 1: Area and contribution of the flow of the Mekong River in each country (Source: http://article.sapub.org/10.5923.j.re.20190904.01.html)

Many researchers have proposed some solutions provided in a few publications. For example, the co-author Scott and Smith (2012), recommended that imperative share is better served by cooperation or at least non-interference than conflict. Furthermore, Gao Yun (2017) specified that the most effective way to foster the Mekong River is to remember common coordination and shared interests for requests to make the Mekong bowl under a decent climate of manageable turn of events. A specific solution given by author D.Li (2019) is to operate China and Laos' repositories for downstream nations' advantageous purposes under the collaboration.

The graph below shows the Mekong water level in Vientiane, Laos:

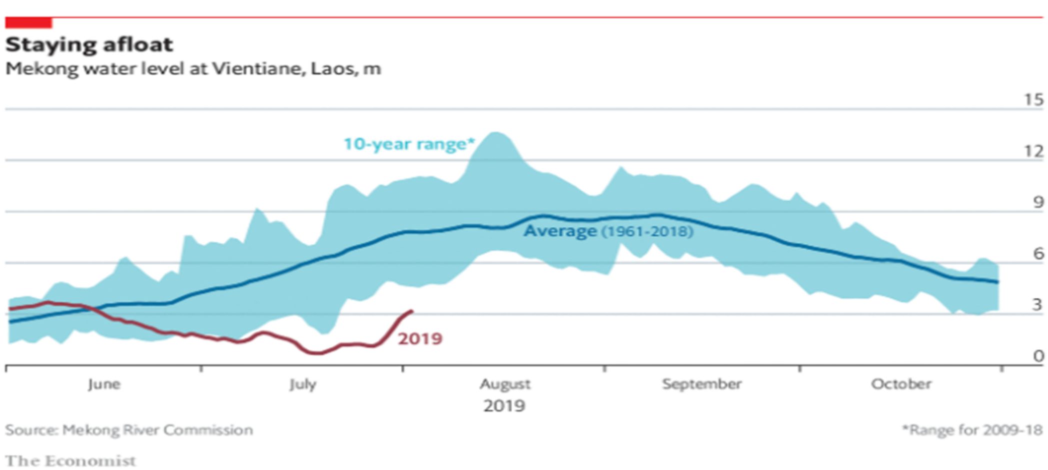


Figure 1: Mekong water level in Vientiane, Lao from 1961 – 2018. (Source:https://www.economist.com/graphic-detail/2019/08/07/why-are-water-levels-of-the-mekong-at-a-100-year-low)

Besides those aforementioned traditional solutions, there are several ways to deal with this conflict issue by applying technical methods using Game Theory models. GT models were applied into various aspects of water management including cost decisions, objective multi-use water, joint administration of water systems, groundwater springs, transboundary water disputes, water treatment factories, and hydropower facilities (Dinar  Hogarth, 2015). Kaveh Madani explained (2010) why water conflicts usually involve conflicts and how game theory can help decipher and distinguish the ways of behaving of partners to water asset issues. In detail, game theory and liquidation haggling were utilized to develop earth reasonable water designation and water clashes avoidance in the transboundary Mekong River bowl mentioned by L.Yuan et al (2017). Another application was highlighted by Limao and Hanman (2013), in order to increase the possibility of an all-win situation rather than an all-lost one, Liao Zh tried applying cooperative game theory with the aim of solving problems of building utilizing dams on the Mekong transboundary rivers.

| **No.** | **Name of publication** | **Factors** |
|---|---|---|
| 1 | Managing and transforming water conflicts | - The use of hydrography against usage as a basis for settlement principles, as well as upstream versus downstream and transitioning from allocations to sharing benefits |
| 2 | Hydrogeomorphic Effects of Reservoirs, Dams, and Diversions | - The effects of complex channel alterations in space and time are investigated, as well as management and restoration methods |
| 3 | Sustainable Water Resources Management | - Defining and measuring sustainability<br>- Identifying the many consequences and tradeoffs |
| 4 | Water conflict - A review | - Territorial conflicts, resource competition, and strategic advantage<br>- Lack of need for freshwater resources, irrigation, and energy production |
| 5 | Water conflict on the Mekong River | - Tensions over the Mekong waters are rising<br>- Inequality of access to freshwater resources |
| 6 | Water diplomacy and conflict management in the Mekong: From rivalries to cooperation | - MRC and water strategy structure<br>- A technical core that provides objective scientific advice as well as lawful, institutional, and vital instruments to energize and uphold arranged arrangements |
| 7 | Water Resources Management in the Mekong Basin | - China has declined to join the MRC<br>- Countries in the lower Mekong region have restricted monetary ability to put resources into provincial activities, and thus depend on external help<br>- Shortage of ownership and control over development programs among countries |

| | | |
|---|---|---|
| 8 | Conflict resolution and policy-making mediation in the Mekong River Basin | - Increasing population<br>- Modifications to the river's natural flow<br>- Pass through waterways and dams<br>- Increasing tourism and industrialization<br>- Returning to traditional land and water executives |
| 9 | 'Water war' in the Mekong Basin? | - Increasing the rate of hydro development<br>- Hydro Development for a bigger scope |
| 10 | Water management of the Mekong River | - Mekong River regulatory power and regulations, as well as the insufficiency of the river's existing management |
| 11 | Water benefits sharing under transboundary cooperation in the Lancang-Mekong River Basin | - Three helpful game hypothesis strategies are utilized: the Shapley esteem, the Gately point, and the Nash-Harsanyi answer for recognizing conceivable advantage sharing arrangements |
| 12 | Game Theory and Water Resources Critical Review of its Contributions, Progres,s and Remaining Challenges | - Game theory models have been utilized in multi-objective multi-use water project cost and advantage appropriation, water system project clashes and joint administration, hydropower facilities, urban water supply, and transboundary water disputes |
| 13 | Game theory and water resources | - Game theory is to interpret and identify the behaviors of stakeholders to water resource problems |
| 14 | Water allocation model in the Lancang-Mekong river basin based on bankruptcy theory and bargaining game | - Game theory was used to create a novel participation insolvency bartering game model to allot water resources |
| 15 | The Mekong game: Achieving an all-win situation | - Helpful game theory has been utilized to take care of issues connected with the development and utilization of dams on trans-line streams |

Table 2: The table describes some factors of all the aforementioned publications.

In short, all of these publications mainly discussed how water conflict problems have been profoundly affecting many aspects of life and several methods including both negotiable and scientific ways such as Game Theory were recommended to solve; however, a specific mathematical technique has not been utilized yet. Hence, our study aims to take advantage of NSGA-II - A multi-objective optimization technique along with the Unified Game-Based Model in order to address the concurrent Mekong River conflict issues among six nations and additionally contribute a new math formula to manage the water crisis currently occurring in other riparian regions in the world.

# 3 Problem description

Water conflict crossing boundaries among countries refers to the accessible rights to a vital water resource and these globally intractable disputes tend to take place more frequently and intensely due to the consequence of water competitive users' opposing interests without any potential strategies to address the problem (Priscolli, 2009). One of the most challenging issues over approximately a century in the Mekong geostrategic region is the unbalanced collaboration in water usage where upstream countries make excessive use of riparian resources to aggressively construct dams and reservoirs, which chiefly poses a significant risk to the livelihoods and natural environment of the downstream ones (Kittikhoun, 2018). Specifically, the construction of hydroelectric dams has developed rapidly and unrestrainedly, which is susceptible to not only environmental river contamination but also politically armed forcing conflicts, followed by a severe danger to Asia's long-term peace and stability.

The establishment of the Mekong River Commission (MRC) in 1995 among Siam and Indochinese countries is missioned to facilitate the ownership of transboundary water resources; however, MRC faces numerous challenges as a result of aggressive hydropower expansion ambitions, particularly in China and Laos (Michal, 2020). Because of China's unwillingness to join the MRC and its non-binding rules and regulations, it has enabled the expansion of substantial hydroelectric investment companies in the Mekong, strengthening China's presence and power in Southeast Asia meanwhile increasing SEA countries' dependence on China (Minh Thu, 2020). As a result, the Lower Mekong River Basin (LMB) countries' economic capacity has been dramatically diminished, along with a lack of ownership over capital and, in some cases, control over development initiatives, rendering them impotent and voiceless in asserting their national and regional interests.

Consequently, the MRC's goal to superintend the river for the extra benefit of the environmental ambiance and inhabitants is being jeopardized by inefficient activities, while the China-led Lancang-Mekong Cooperation proves to be more powerful, promoting its potential throughout the area. In conclusion, the unproductive distribution of water usage in the Mekong River among the six countries, in which China optimizes the over-exploitation of riparian resources for the purpose of hydroelectric dams construction and fisheries while LMB nations struggling to seek for external support, can lead to political, economic and military disparities. If the member-state conflicts and China's growing influence are not resolved, outside engagement, such as the European Union (EU), may be required to leverage China's influence on water concerns (Michal, 2020).

Our study with the application of Game theory's principles and NSGA-II is tasked to appropriately regulate the efficient share of river assets and relevantly control the hydropower projects. Specifically, the mission of this research paper is to sequentially handle basin exploitation among six Mekong countries in three major sections including agriculture, hydropower, and aquaculture.

In the agriculture field, in the period 2020 - 2021, the water flow went down significantly from 30,000 to 15,000 $m^3/s$ in Kratie of Cambodia rainy season flows and according to the Mekong River Commission, the river supplied up to 160 million tons of sediment per year to the estuary in 1994, but only 75 million tons per year remained in 2014. This causes decreasing alluvial accretion capacity and increased salinity due to water shortage and causing drought in downstream countries. (Chu and nnk, pp 144-167, 2009). In the hydropower field, the dam impedes fish movement and a 2018 analysis found that the dams prevent fish migration and could lead to a $22.6 billion decrease in fisheries income over 24 years in the nations south of China(Murray, 2021). This changes the customs and habits of people living on and on both sides of the river and reduces the income of people who live across the Mekong river basin. Furthermore, there are 68 species of fish from the LMB countries that are globally vulnerable and fish supplies are reducing dramatically by 35-40% by 2020, and fishermen along the Tonle Sap stated that their catches in 2019 were down by at least 80%. The Tonle Sap is the largest inland fishery in the world and provides about three-quarters of the country's protein (Murray, 2021). This resulted in the level of biodiversity affected by fishing and the habitat of the species was changed due to the change of river flow (Ian. G & Hogan. Z, 2021).

In this study, we examine the interactions between six countries: five Southeast Asian countries including Vietnam, Laos, Thailand, Cambodia, Myanmar, and the remainder China, which share a basin of a riparian surrounding in the area of the Mekong River basin. Every country strives to get the most out of its water resources; however, the fact that China is the Mekong's source country and has control over its water resources, as well as China's ability to choose how much water to share with downstream countries, is causing a conflict between countries in the basin of Mekong River. We use the game theory model and Nash equilibrium to find a solution that will satisfy all six countries in this problem. Each country is defined by four characteristics:

- *Geographical location*: whether that country is located upstream or downstream.
- *Economic potential*: reflects its strength and how that country can surpass other countries in terms of negotiation, followed by the country's Gross Domestic Product (GDP), and what percentage of that agriculture accounts in that country's GDP.
- *Defense potential*: a country's ability to threaten other countries with military force and refuse to negotiate about water issues in the Mekong Basin, followed by the Military Strength Ranking.
- *Flood damage*: the amount of damage caused by a flood to the country's GDP.

| | China | Myanmar | Thailand | Laos | Cambodia | Vietnam |
|---|---|---|---|---|---|---|
| Geographical location | Upstream | Down-stream | Down-stream | Down-stream | Down-stream | Down-stream |
| Economic potential (agriculture in GDP) | $17.6 trillion (7.3%) | $71.4 billion (25.5%) | $547.43 billion (8.4%) | $22.01 billion (19.5%) | $29.31 billion (26.7%) | $282.37 billion (18.1%) |
| Defense potential | 3rd | 39th | 29th | 121st | 101st | 28th |

Table 3: Country's Characteristics.

As can be observed from the examined characteristics above, China is dominant in all aspects of the geostrategic approach, economic potential, and military power; as a result, China has complete control over whatever strategy generates the greatest benefits. If China refuses to collaborate with downstream areas, China will gain an adequate supply of water and be able to develop a large economy, but there will likely be an internal war in the region. Because of the increased expenditure on armaments and soldiers, the Chinese economy will practically stagnate, not to mention the serious loss of bilateral friendship, which could lead to the loss of a densely populated marketplace for trade and commerce in Southeast Asia. In case of strategic cooperation, China can still obtain more or less water from the Mekong River, and may still provide a proportion of it to the other LMB countries while maintaining a long-term peaceful relationship. This technique will result in a Nash equilibrium, in which all stakeholders benefit equally. However, depending on how many benefits participants desire, each player can choose a cooperative or non-cooperative approach, but not necessarily a Nash equilibrium strategy.

China and Laos currently own 76 hydroelectric dams that generate roughly $8000m^3/s$. Only 4 percent of total hydroelectricity discharges to water, creating drought and saltwater intrusion in downstream countries (Wangkiat, 2021). An effective strategy is that the Laotian and Chinese governments should limit the construction of new dams and take advantage of the yearly water supply of $2500m^3/s$ on average. Furthermore, downstream nations such as Cambodia and Vietnam must increase hydroelectric dam utilization to be able to exploit at least $2500m^3$ of water yearly.

Based on the above inputs, assume that there are three countries 1, 2, and 3 that belong to a transboundary river M. Country 1, is the upstream country that had the strongest military power and largest economy compared to the other countries, and countries 2 and 3 are downstream countries, which are not as strong as country 1 in both economy and military. Because of that, Country 1 has the right to control the supply of water. However, the result is an economic, social, security, political, and environmental struggle with two other nations. However, Country 1 can exchange surplus water with Countries 2 and 3. Unless there are additional benefits to cooperating with Country A, Countries 2 and 3 are more inclined to work with Country 1.

In the payoff of a given situation, there are two kinds of benefits and one kind of financial cost.

Water benefit is the first benefit that a nation gains by obtaining water from a transnational source. Economic advantages from agricultural, urban, and industrial growth are among the benefits associated with water use. It's important to remember that Country 1 receives a water benefit that includes the financial advantage of utilizing more water than it does from the river. Therefore, the financial advantages of absorbing upstream extra water released by Country 1 are the water advantages of Countries 2 and 3.

The potential benefit is the second benefit resulting from a nation's cooperation policy. Long-term considerations including societal interests, natural advantages, political confluences like harmonious relationships, and international alliances with neighbors all contribute to the benefits of cooperation. E and F are GDP in agriculture and the percentage damage of flood to GDP each year in each country. Two above variables will highlight the payoff that three countries can get when choosing a cooperative strategy.

Based on that, we have a sampled data set table:

| **Country** | **Variables** | **Figure** |
|---|---|---|
| Country 1 (up-stream country) | $x_1^{(1)}$, $x_2^{(1)}$: Possibilities of Country 1 participating or not participating, respectively | 50%, 50% |
| | $GDP_1$ : GDP of Country 1 | 18.000B USD |
| | $E_1$ : GDP of agriculture | 15% |
| | $F_1$: Damage of flood to GDP in one year in Country 1 | 1% |
| Country 2 (down-stream country) | $x_1^{(2)}$, $x_2^{(2)}$: Possibilities of Country 2 participating or not participating, respectively | 50%, 50% |
| | $GDP_2$ : GDP of Country 2 | 200B USD |
| | $E_2$ : GDP of agriculture | 27% |
| | $F_2$: Damage of flood to GDP in one year in Country 2 | 1% |
| Country 3 (down-stream country) | $x_1^{(3)}$, $x_2^{(3)}$: Possibilities of Country 3 participating or not participating, respectively | 50%, 50% |
| | $GDP_3$ : GDP of Country 3 | 100B USD |
| | $E_3$ : GDP of agriculture | 20% |
| | $F_3$: Damage of flood to GDP in one year in Country 3 | 1% |

Table 4: Data set of each country.

From Table 4, it is easy to see that Country 1 is entitled to choose to release surplus water to downstream countries while Country 2 and Country 3 can choose to cooperate or not if they see the potential benefit of not cooperating with Country 1. In addition, if Country A holds 100% of water without release, the benefit of agriculture will be eliminated by flood and the damage made by the flood will increase. Countries 2 and 3 can stabilize the damage of floods but the benefit from agriculture will be eliminated because of lack of water, it can even cause war to dispute the water resources. If Country 1 chose the cooperative strategy that releases abundant water to downstream countries. It means that all three countries can earn benefits. The GDP of Country 1 is still unstable. Although the two downstream countries can increase flood damage because of the water from upstream, it is enough water to supply agriculture.

From that, assume that 10 is the highest payoff, 5 is a lower payoff and 1 is the least payoff. Now, the payoff for each country will be:

| Country 1 | Country 2 | Country 3 | |
|---|---|---|---|
| | | Cooperation $x_1^{(3)}$ | Non- Cooperation $x_2^{(3)}$ |
| Cooperation $x_1^{(1)}$ | Cooperation $x_2^{(2)}$ | $U_{111}^{(1)}$=10,$U_{111}^{(2)}$=10, $U_{111}^{(3)}$=10 | $U_{112}^{(1)}$=10,$U_{112}^{(2)}$=10, $U_{112}^{(3)}$=1 |
| | Non- Cooperation $x_2^{(2)}$ | $U_{121}^{(1)}$=10,$U_{121}^{(2)}$=1, $U_{121}^{(3)}$=10 | $U_{122}^{(1)}$=10,$U_{122}^{(2)}$=1, $U_{122}^{(3)}$=1 |
| Non-Cooperation $x_1^{(2)}$ | Cooperation $x_2^{(2)}$ | $U_{211}^{(1)}$=5,$U_{211}^{(2)}$=5, $U_{211}^{(3)}$=5 | $U_{212}^{(1)}$=5,$U_{212}^{(2)}$=5, $U_{212}^{(3)}$=1 |
| | Non- Cooperation $x_2^{(2)}$ | $U_{221}^{(1)}$=5,$U_{221}^{(2)}$=1, $U_{221}^{(3)}$=5 | $U_{222}^{(1)}$=5,$U_{222}^{(2)}$=1, $U_{222}^{(3)}$=1 |

Table 5: Payoff of each country under the strategies.

The following formula (Fahimeh and et al, 2021) summarizes Country 1's predicted gains from cooperative behavior $U_1^{(1)}$ and non-cooperative behavior $U_1^{(2)}$:

From that formula, we can calculate the payoff of each country:
Country 1: $U_1^{(1)} = 10$, $U_1^{(2)} = 5$
Country 2: $U_1^{(1)} = 7.5$, $U_1^{(2)} = 1$
Country 3: $U_1^{(1)} = 7.5$, $U_1^{(2)} = 7.5$

As can be seen, it is clear that when three countries cooperate with each other, the payoff will be highest (25). Therefore, the Nash equilibrium can be reached if country 1 agrees to release the water and the rest countries choose to cooperate with Country 1.

# 4 Model

The idea that we applied the Unified game-based model is for resolving conflicts between countries over the exploitation of economic resources on this river system, with the multi-player in a common problem. The Unified game-based model concept is a distinguished player created with different characteristics from the rest of the players (Bao Ngoc Trinh, Quyet Thang Huynh, Xuan Thang Nguyen, 2019). It is true in that case that China is the country that is entitled to decide whether to release water to downstream countries or not. This model helps us find the most effective strategies for each country to solve this conflict.

## 4.1 Mathematical model

Based on disputes between nations in the Mekong River basin over the exploitation of the river system's economic resources, with multiple players involved in a single issue. As a result, we use the Unified Game-Based Model, which is shown as follows:

$$G =< \{P_0, P\}, \{S_0, S_i\}, \{u_0, u_i\}, R^c > \quad (1)$$

Specifically:

- G: is a model representation of a game with multiplayer.
- $P_0$: is a special player strategy set, representing countries. The representative of the Mekong River Commission, which represents all of the interests of the nations in the Mekong River system, is a special player in the Mekong River issue.
- P: is the set of players in a game that is represented: $\{p_1,\ p_2, \ldots, p_n\}$. These players are at odds with each other over the issue of resources in the Mekong system.
- $S_0$: is a set of the special player's strategy $S_0 = \{s_{01}, \ldots,\ s_{0n_0}\}$ where $n_0$ represents number of special player's strategy.
- $S_i$: is a set of player strategy, set $S_i = \{s_i = s_{in_i}\}$ where : $n_i$ is player's strategy number $i \in \mathbb{N}$.
- N - set of players. N = {1,2,3…i}. There are representative countries that have benefits from the Mekong River.
- $u_0 : S_0 \to \mathbb{R}$ is the payoff component of the special player's tactic.
- $u_i : S_i \to \mathbb{R}$ is player i's payoff function, referencing player i's strategy to a real number.
- $R^c$ – is the vector indicating the direction of solving the problem's contradictions. In which, c is the set representing the conflicts between countries in the problem. The disagreement between M players ($1 \leq M \leq N$) is represented by the non-empty vector $\vec{v} \in R^c$.

Considering the situation in which there are three countries j, k, l in the Mekong river basin playing the collaboratively strategic game. Each player can choose either to cooperate or non-cooperate with other players in water sharing. The probability $x_i$ may take the value 1 (participation) and value 2 (non-participation), where $x_1 + x_2 = 1$.

The expected payoff for a country i is calculated by the following formula:

$$u_i = \sum_{j=1}^{2} \sum_{k=1}^{2} \sum_{l=1}^{2} x_j^1 x_k^2 x_l^3 u_{jkl}^i \tag{2}$$

Where:

- $u_i$: the expecd payoff of a certain country i.
- $x_j^{(1)}$: possibilities of country 1 participating (1) or not participating (2) (represented by j).
- $x_k^{(2)}$: possibilities of country 2 participating (1) or not participating (2) (represented by k).
- $x_l^{(3)}$: possibilities of country 3 participating (1) or not participating (2) (represented by l).
- $u_{jkl}^i$: the payoff of a country i in the case of cooperation or non-cooperation of other countries represented by j, k, l.

## 4.2 Nash Equilibria formula, and its application in the field of topic

The Nash Equilibrium is a set of player actions in which each player's activity is the optimum reaction to the actions of the other players. One of the most widely used applications of NE is decision making, and in this study, decision making in solving the conflict in water resources between nations in the Mekong river basin.

When considering the decisions of other players, each player's strategy is optimal in the Nash Equilibrium. Every player wins because they all obtain the result they want. A model in the formula defines a game with n players following:

When the player $i \in (1 \leq i \leq N)$ chooses the strategy $s_i \in S_i$, we call $s_{-i} \in S_i$ the strategy of other players. The player i's payoff function can be defined like this: $u_i(s_i, s_{-i})$. Also, the group of strategy $S^* = (s_1^*, s_2^*, ..., s_n^*)$ is called the Nash Equilibrium when: $\forall (s_i^*, s_j^*) \in S^*, (s_i^*, s_j^*) \notin R^c, (1 \leq i, j \leq \mathbb{N})$, and: $u_i(s_i^*, s\_i^*) \geq u_i(s_i, s\_i^*) \forall s_i \in S_i$.

## 4.3 Nash Equilibria using Nikaido Isoda function

The equilibrium issue was first presented by H. Nikaido, and K. Isoda in 1955 determined to sum up the Nash equilibrium issue in non-cooperative games. The calculation of balancing the components of the issue is generally the calculation of finding $x^* \in K$ to such an extent that $f(x^*, y) \geq 0$, $\forall y \in K$. Where K is a given set and $f : K \times K \to \mathbb{R}$ is a given capacity fulfilling $f(x, x) = 0$.

The above inequality was first presented by H. Nikaido and K. Isoda in 1955 while summing up the Nash equilibrium issue in a non-cooperative game. In particular, the Nikaido-Isoda work characterizes the Nash equilibrium of the undertaking the board struggle issue depicted by the Unified Game-based model as follows:

$$f(x^*, x) = \sum_{i=1}^{n} (f_i(x) - f_i(x[y_i])) \quad (3)$$

Where the vector $x[y_i]$ is the vector gotten by supplanting the part $x_i$ by $y_i$ from the x. The symbol $K_i \subset \mathbb{R}$ is the methodology set of the $i^{th}$ player. Then, at that point, the methodology set of the game is: $K = K_1 \times ... \times K_n$. A point $x^* \in K$ is known as the Nash equilibrium of the game if:

$$f_i(x^*) = \max f_i(x^*[y_i]), \forall y_i \in K_i, \forall i(y_i \in K_i) \quad (4)$$

Finding the Nash equilibrium utilizes however the Nikaido-Isoda work is identical to seeing as the $f_i(x^*)$ such an extent that Formula (2) is fulfilled.

So according to the Nikaido-Isoda bi-function in Nash equilibrium, applied to the Unified Game-based model, while tracking down the value:

$$f(x^*, x) = f(S^*, S) = \sum_{i=1}^{n} (u_i(s_i^*, s\_i^*) - u_i(s_i, s\_i^*)) \geq 0, \forall s_i \in Siimg2 \quad (5)$$

In practice, the Nash equilibria need to fulfill extra limitations and the estimation of $f_i(x^*)$ or $u_i(s_i^*, s\_i^*)$ depends on many elements and information of the issue, presently the issue of tracking down Nash equilibrium as per the Nikaido-Isoda bi-function has the type of a multi-objective enhancement issue and can be settled by multi-objective transformative streamlining calculations (MOEA).

# 5 Algorithm with Nash Equilibria

## 5.1 The NSGA-II in solving the problem

To handle multi-objective streamlining issues, the NSGA-II strategy (Non-overwhelmed arranging hereditary calculations) is carried out. NSGA-II produces posterity utilizing a particular kind of hybrid and change, then, at that point, chooses the cutting edge utilizing nondominated arranging and swarming distance correlation (Azura and nkk, 2011). The feasibility of a model for optimal water resource allocation that addresses intergenerational equity, as well as the problem of water supply and demand, is established in this study. The NSGA-II algorithm is likewise used to decide the ideal water asset circulation for upstream and downstream nations in the Mekong River bowl.

## 5.2 The NSGA-II in finding the Nash Equilibria

The algorithm follows the general outline of a hereditary calculation with a changed mating and endurance assurance. In NSGA-II, first, individuals are chosen frontwise. Thus, there will be what is happening where a front should be split as not all individuals are permitted to get by. On this front, solutions are chosen according to crowding distance. Besides, to expand some choice tension, NSGA-II proposes a binary tournament mating determination. Every individual is first analyzed by rank and afterward crowding distance. There is likewise a variation in the original C code where rather than using the rank, the domination criterion between two solutions is used.

NSGA-II procedure:

- Play out a non-ruled arranging in the blend of parent and posterity populaces and gathering them by fronts, for example they are arranged by a increasing level of non-domination:

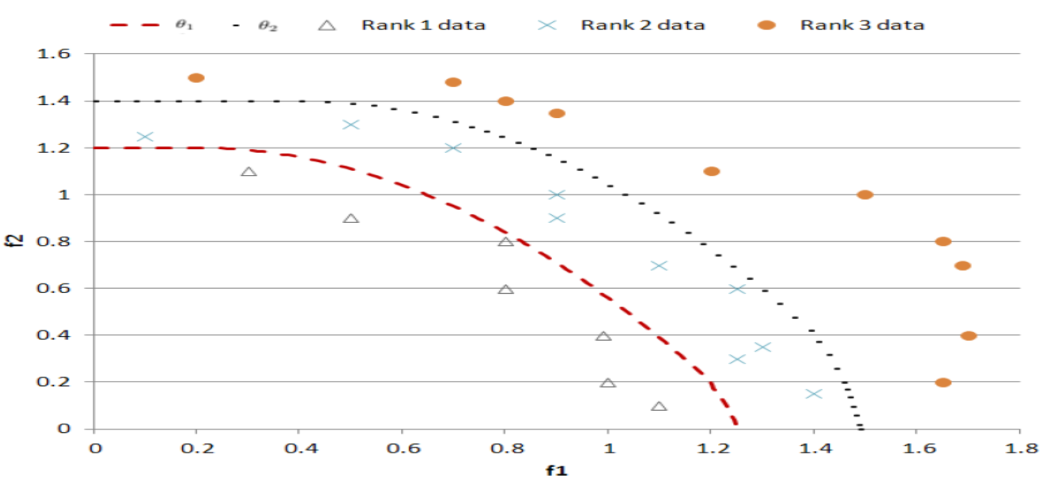


Figure 2: Minimizing f1, f2. Three front levels.
(Source: https://www.researchgate.net/publication/261202465_Multi_co-objective_evolutionary_optimizationtimization_Cross_surrogate_augmentation_for_computationally_expensive_problems)

.Schematic of the NSGA-II procedure.

- Fill new population as per front raking.

- Perform Crowding-sort, which uses crowding distance assuming one front is taking to some extent like F3.

- Initialize offspring population from this new population using crowded tournament determination (It looks at by front raking, if there is equivalent then by crowding distance), intersection and mutation operators.

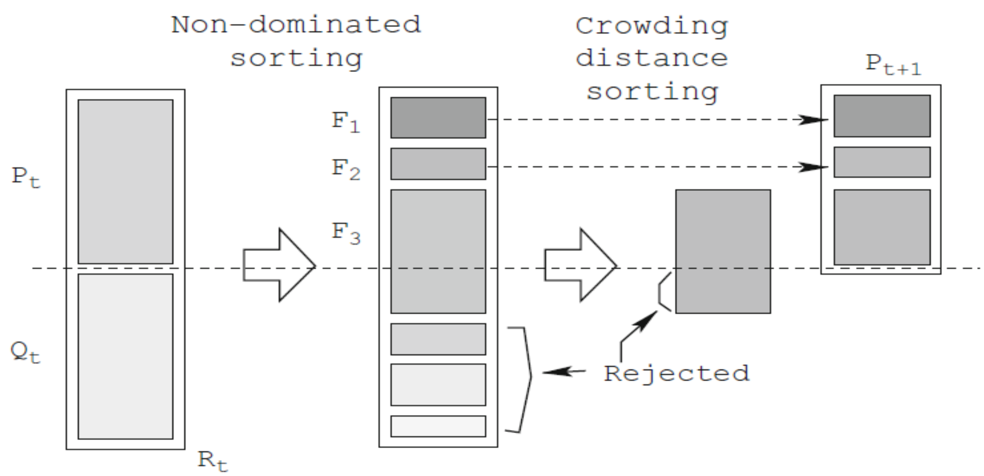


Figure 3: Schematic of the NSGA-II procedure.
(Source:
https://www.researchgate.net/publication/220045365_Multiobjective_Optimization_Using_Evvolutionary_Algorithms_Wiley_New_York)

## 5.3 Algorithm formulas/parameters

In the NSGA-II calculation, there are several formulas and parameters that can be customized to find the Nash equilibrium for this problem:

- $f_k(X)$ : the function to be solved in the algorithm. In this problem we need to find the Nash equilibrium where the payoffs of the three countries are equal so $f_k(X) = (U_1 = U_2 = U_3)$.

- N': member involved. In this problem, there are three countries so N' = 3.

- P': population. In this problem, the population is the number of all countries' payoffs in all possible scenarios.

## 5.4 Pseudo code and diagram of NSGA-II

Pseudo code:

**Algorithm 1** Procedure of NSGA-II

**Require:** N' = 3, g, $U_1 = U_2 = U_3 \rightarrow$ individuals advanced g generations to settle $U_1 = U_2 = U_3$

Create Population: all payoffs of all countries in all possible scenarios;
Assign N' = 3;
Assess Objectives Values;
Allocate Rank (level) in light of Pareto - sort;
Produce Child Population;
Twofold Tournament Selection;
Recombination and Mutation;
**for** i = 1 to g **do**
  **for** each Parent and Child in Population **do**
    Allocate Rank (level) in view of Pareto - sort;
    Produce sets of nondominated arrangements;
    Decide Crowding distance;
    Loop (inside) by adding answers for cutting edge beginning from the principal front until N' people;
  **end for**
  Select focuses on the lower front with a high swarming distance;
  Create a new generation;
  Twofold Tournament Selection;
  Recombination and Mutation;
**end for**

Diagram:

Also, the figure below is a flow diagram of the NSGA-II Algorithm:

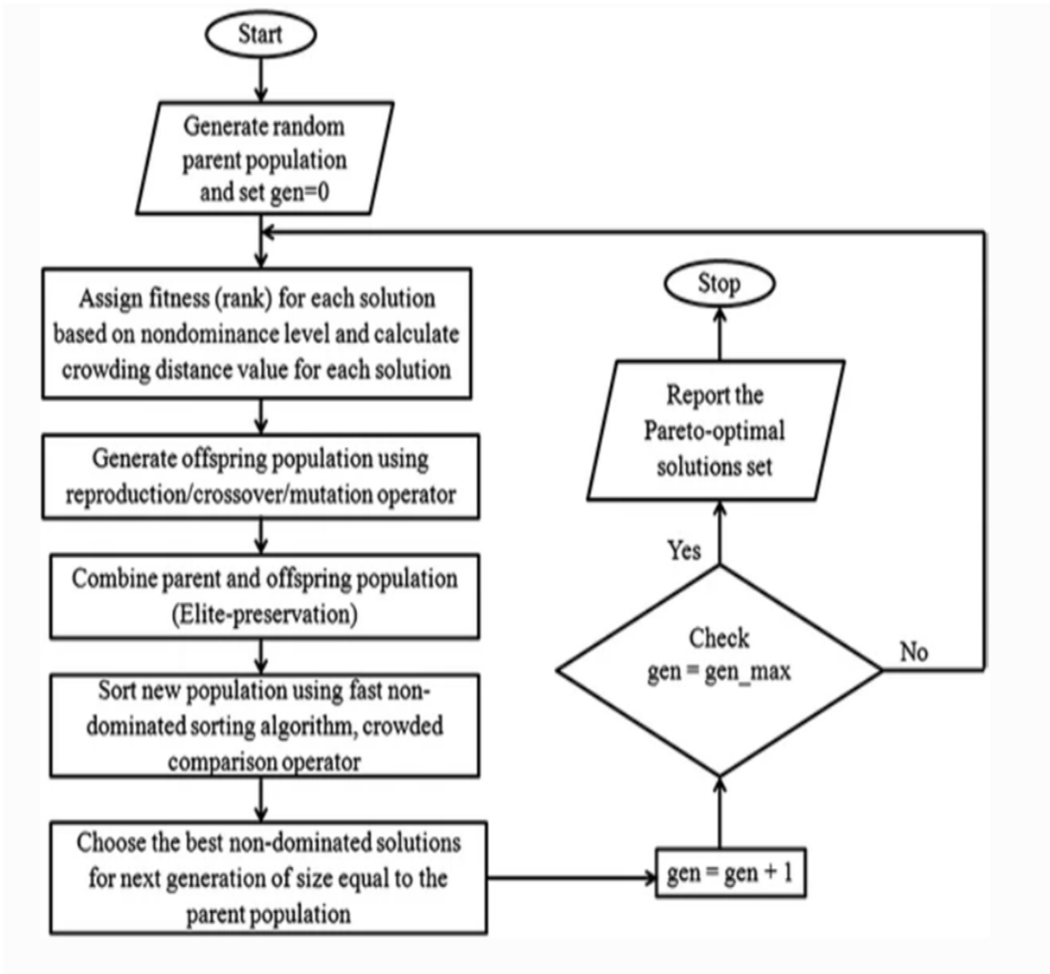


Figure 4: The flow diagram of NSGA-II Algorithm.
(Source: https://doi.org/10.1007/s13198-017-0672-y)

# 6 Conclusion

Ultimately, the issue of water distribution for hydroelectric dams and fishing in the Mekong River is a contentious topic that, if not taken into account, could lead to military-political confrontations in the internal region. As being the upstream country with the overwhelming advantage in all respects, China can impose its authority on downstream countries if water-sharing does not lead to a beneficial compromise. In this study, our project uses a Unified Game-Based Model and the NSGA-II algorithm to apply game theory to modeling solutions to resolve water conflict among counties in the Mekong River basin. Specifically, the NSGA-II algorithm is an optimal solution for a multi-objective optimization issue since it produces a wide range of answers with varying tradeoffs, allowing all possible trade-offs to be considered. Our exploration is principally centered around handling the issue of water clashes in the Mekong River bowl. Collaboration in using water resources efficiently is indispensable so that all six riparian basin countries have adequate water to construct hydroelectric dams and fisheries to enhance the agro-forestry-fishery economy. Only when no more or less water is exploited than the permissible amount of water, the water conflicts will be addressed.

# References


[1] Bao Ngoc Trinh, Quyet Thang Huynh, Xuan Thang Nguyen. June 2019. *Nash Equilibrium model for conflicts in project management.*
Derived from: (PDF) Nash Equilibrium model for conflicts in project management (researchgate.net).

[2] Fahimeh Mirzaei-Nodoushan, Omid Bozorg-Haddad, Vijay P. Singh & Hugo A. Loáiciga. 12 October 2021. *Analysis of long-term strategies of riparian countries in transboundary river basins.*
Derived from: Analysis of long-term strategies of riparian countries in transboundary river basins — Scientific Reports (nature.com).

[3] O.R.Shaltami and M.G.Jay. October 2020. *Water conflict - A review.*
Derived from: https://www.researchgate.net/publication/344769421_Water_conflict_-_A_review

[4] Priscolli, J.D. Aaron, T.W. January 2009. *Managing and transforming water conflicts, Hydrological Sciences Journal - Journal des Sciences Hydrologiques.*
Derived from: https://www.researchgate.net/publication/287776340_Managing_and_transforming_water_conflicts.

[5] Petts, G.E. Gurnell, A. March 2013.*Hydrogeomorphic Effects of Reservoirs, Dams, and Diversions.*
Derived from: https://www.researchgate.net/publication/287292244_Hydrogeomorphic_Effects_of_Reservo irs_Dams_and_Diversions

[6] Loucks, D.P. January 2009. *Sustainable Water Resources Management*
Derived from: https://www.tandfonline.com/doi/abs/10.1080/02508060008686793.

[7] Shkara, N.D. May 2018. *Water conflict on the Mekong River*
Derived from: https://www.researchgate.net/publication/325572144_Water_conflict_on_the_Mekong_River.

[8] Kittikhoun, A. Staubli, D.M. 2018. *Water diplomacy and conflict management in the Mekong: From rivalries to cooperation*
Derived from: https://www.sciencedirect.com/science/article/abs/pii/S0022169418307534.

[9] To Minh Thu Han Phoumin. November 2020. *Water Resources Management in the Mekong Basin.*
Derived from: https://www.eria.org/uploads/media/Books/2020-Subregional-Development-ASEAN-after-COVID19-Mekong/15-Water-Resources-Management.pdf.

[10] Michal Zareba. 2020. *The Role of the Mekong River Commission in Regional Transboundary Water Governance: Prospects and Challenges.*
Derived from: https://halshs.archives-ouvertes.fr/halshs-03151199/document

[11] Scott W.D. Pearse-Smith. August 2012. *Water war' in the Mekong Basin?*
Derived from: https://www.researchgate.net/publication/263348285_%27Water_war%27_in_the_Mekong_Basin

[12] Gao Yun, Stewart Williams, Dai Wenbin. 2017. *Water management of the Mekong River.*
Derived from: https://pdfs.semanticscholar.org/cc08/fe6575355167b1081524042fee08cfa7688c.pdf.

[13] D.Li, J.Zhao and Rao S. Govindaraju. October 2019. *Water benefits sharing under transboundary cooperation in the Lancang-Mekong River Basin.*
Derived from: https://www.sciencedirect.com/science/article/abs/pii/S0022169419307097.

[14] Dinar, A. Hogarth, M. 2015. *Game theory and water resources critical review of its contributions, progress, and remaining challenges.*
Derived from: https://escholarship.org/content/qt7tt7880f/qt7tt7880f.pdf.

[15] Madani, K. February 2010. *Game theory and water resources.*
Derived from: https://www.researchgate.net/publication/222957808_Game_theory_and_water_resources.

[16] Yuan,L. W.He, D.M.Degefu, Z.Liao. May 2017. *Water allocation model in the Lancang-Mekong river basin based on bankruptcy theory and bargaining game.*
Derived from: https://www.researchgate.net/publication/317073633_Water_Allocation_Model_in_the_Lancing-Mekong_River_Basin_Based_on_Bankruptcy_Theory_and_Bargaining_Game.

[17] Liao Zh Hannan, P.M. May 2013. *The Mekong game: Achieving an all-win situation.*
Derived from: https://www.researchgate.net/publication/257673149_The_Mekong_Game_Achieving_an_All-win_Situation.

[18] Chu Thai Hoanh, Thierry Facon, Try Thuon, Ram C. Bastakoti, François Molle Fongsamuth Phengphaengsy. *Irrigation in the Lower Mekong Basin Countries: The Beginning of a New Era? Contested Waterscapes in the Mekong Region, Pp144-167.*
Derived from: https://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers16-05/010050256.pdf.

[19] Ian. G Hogan. Z. 2021. *The Impacts of Hydropower Dams in the Mekong River Basin: A Review.*
Derived from: https://www.researchgate.net/publication/348687378_The_Impacts_of_Hydropower_Dams_in_the_Mekong_River_Basin_A_Review.

[20] Kumar, H. Yadav, S.P. 2017. *NSGA-II based fuzzy multi-objective reliability analysis, Int J Syst Assur Eng Manag 8, 817–825.*
Derived from: https://doi.org/10.1007/s13198-017-0672-y.

[21] M.Buxton, J.Martin M.Kelly. 2006. *Conflict resolution and policy making mediation in the Mekong River Basin.*
Derived from: https://www.researchgate.net/publication/305354493_Conflict_resolution_and_policy_making_mediation_in_the_Mekong_River_Basin.

[22] M. Hiebert. April 2021. *Upstream Dams Threaten the Economy and the Security of the Mekong Region.*
Derived from: https://fulcrum.sg/upstream-dams-threaten-the-economy-and-the-security-of-the-mekong-region/.

[23] Kalyanmoy. D. February 10, 2011. *Multi-objective optimization using evolutionary algorithms: An introduction.*
Derived from: https://www.researchgate.net/publication/220045365_Multiobjective_Optimization_Using_Evvolutionary_Algorithms_Wiley_New_York.

[24] Minh Nghia Le, Yew. O, Stefan. M, Chun-Wei. S & Bernhard. S. July 10, 2012. *Multi co-objective evolutionary optimization: Cross surrogate augmentation for computationally expensive problems.*
Derived from: https://www.researchgate.net/publication/261202465_Multi_co-objective_evolutionary_optimization_Cross_surrogate_augmentation_for_computationally_expensive_problems.