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Analysis of Barriers to Green Data Centers Implementation in Malaysia, using Interpretive Structural Modelling (ISM)

Hasbullah Harun
Faculty of Business Management, University Technology Mara (UiTM), Shah Alam, Malaysia
hasbullahharun@yahoo.com

Abstract: The data center market is expected to grow at 7% during 2022- 2027 and the market size is to reach RM2.0 billion in 2027. The high impact of ICT contributes to high energy consumption, which will impact the environment and greenhouse gas emissions. To reduce energy consumption is to introduce a green data centre. Implementing a green data center involves the introduction of energy-efficient measures for the data center. This will include using energy-efficient ICT equipment and energy-efficient facilities equipment, especially the HVAC system. The successful introduction of the green data center involves new technologies in which there will be barriers that need to be addressed. Based on the study, green awareness and the benefit of switching to green data centers is essential for green data center initiatives in Malaysia.

Keywords: *Green Data Centers, Energy Consumption, Greenhouse gas, Interpretive Structural Modelling (ISM).*

1. Introduction and Background

Typically, a data center represents an area with a large concentration of electronic equipment and power density within a limited space. Malaysia has a strong potential to become a regional hub for Data Centers (DC) as well as co-location (CoLo) providers based on several factors including cheaper land, lower electricity cost and good infrastructure, skilled workforce, political stability, good international connectivity (Malaysia International Trade Investment, 2018). The data center market is expected to grow at 7% during 2022-2027 and the market size is to reach RM2.0 billion by 2027 (Arizton, 2022). The global green data center market is expected to reach US35 billion by 2026 (Insight, 2020). The Malaysian data center industry is growing aggressively where the market size would cross USD 800 Million, and the market is targeted to grow at 8% during 2020-2025. The key players are VADS Berhad, Keppel Data Centers, Alpha Data Centre Fund, Katalyst Data Management, and Regal Orion (Market, 2020).

2. Literature Review

High energy consumption at data centers is not new, study total world electricity consumption of servers and associated cooling and infrastructure equipment from data center operations has roughly doubled from 2000 to 2005, to about 123 billion kWh and has become a growing concern (Koomey, 2007). Power and cooling costs have been the main cost contributors to new data centers. It is a big challenge, but there are ways to mitigate this. The primary equation sounds simple: it reduces data capacity and reduces energy consumption. The trick, of course, is to shrink the services which may not be possible. Software and hardware technologies like virtualization, consolidation, live migration and cloud computing could be enhanced to reduce the consumption of energy (Uddin & Rahman, 2011) Running data center operations requires system operational frameworks, especially in preparing the operational structure of implementing new technologies in a more systematic, comprehensive, controlled, and timely manner to overcome deficiencies in greening data center (Uddin & Rahman, 2012). Enterprises, governments, and societies at large are poised to tackle environmental issues which subsequently contribute to greenhouse gas emissions from the increase in ICT usage (Uddin, Shah, & Memon, 2014).

The impact of data center operations where Google and Microsoft paid millions of dollars for energy bills (Qureshi, 2004) and this leads to 50 tons of carbon dioxide emissions a year (Hu, Li, & Sun, 2021). With the challenges of climate change, there have been growing numbers of green data centers deployed as mitigation (Hu et al., 2021). Green data centers focus on reducing power consumption by increasing energy efficiency (Ren, Wang, Urgaonkar, & Sivasubramaniam, 2014) and to explore into opportunities in implementing renewable energy and fuel cells (Deng, Liu, Jin, Li, & Li, 2014). However, the second approach has limitations where the renewable energy is intermittent and fuel cells lead to high temperatures (Tripathi, Vignesh, & Tamarapalli, 2017). Most of the measures for a green data centre are to minimize the use of power consumption thru energy-efficient ICT equipment and energy-efficient supporting equipment, especially the HVAC system (Hu et al., 2021).

Green Data Centre Technical Code in Malaysia: A technical code for the Specification for Green Data Centers under section 185 of Act 588 (Communications and Multimedia Act 1998) was to provide the guidance required by private, government and commercial data centers on the minimum requirements for green data centers to establish policies, systems, and processes to improve data center energy efficiency. It will result in a reduction of the facility's operating costs and the carbon footprint of the industry. Briefly, the technical codes described the following recommendations (MCMC et al., 2015):

- Power usage effectiveness (PUE) to be 1.6 and below
- Supply air temperature (SAT) above 23oC
- Relative humidity ratio (RHR) between 30% to 60%
- UPS system efficiency (USE) above 90%

3. Research Methodology

Based on barrier analysis in sustainability studies, the Interpretive Structural Modelling (ISM) method is a widely used and well-established methodology for identifying relationships among specific items that define a problem or an issue when IS is a well-established methodology used by researchers (Attri, Dev, & Sharma, 2013). By definition, ISM is an interactive learning process in studying the interrelationships among various elements related to the issue (Warfield, 1974). The model is formed to portray the structure of a complex issue or problem in a carefully designed pattern implying graphics as well as words (Raj, Shankar, & Suhaib, 2008).

The ISM Processes: The ISM process is a procedure to obtain the best potential barriers for the promotion of green data centers' financial mechanisms, they recommend the step-by-step procedure as follows (Attri et al., 2013):

- Identify the factors and sub-factors that affect spending on energy efficiency and green data centers.
- Create a contextual relationship between each of the factors and sub-factors that were identified in an earlier step.
- Create a Structural Self-Interaction Matrix (SSIM).
- Formulate the SSIM Reachability Matrix and examine the same section for contextual transitivity relationships.
- The final reachability matrix obtained from step 4 is partitioned into different levels.
- Create a Digraph based on the relationship of the final Reachability Matrix and remove the transitive relationship.
- The resulting digraph was converted to the ISM model form by substituting the sub-factor.
- The ISM model generated through development in step 7 checks whether it is necessary to make modifications.

A literature review was conducted based on studies of green technology and green data center implementation. The compilation of barriers from the literature review is as per Table 1: Compilation of barriers to energy efficiency implementation from the literature review.

Table 1: Compilation of Barriers to Energy Efficiency Implementation from the Literature Review

	(Kangas, Lazarevic, & Kivimaa, 2018)	(Morabito, Wang, & Payne, 2020))	(Ige, Inambao, Olanrewaju, Duffy, & Collins, 2020)	(Sengar et al., 2020)	(Clairand, Briceño-león, Member, Escrivá-escrivá, & Pantaleo, 2020)	(Liu, Development, Group, & Noor, 2020)	(Murshed, 2020)	(Bertoldi, Boza-kiss, Economidou, Palermo, & Todeschi, 2020)
Communication	X	X				X		
Information	X		X			X		
Awareness	X					X		
Financial Support	X			X				X
Institutional involvement	X	X		X				
skills	X			X				
Market	X		X	X				
OrganiSational			X					
Behavioural			X					
Economic			X	X	X	X		
Cost			X			X		X
Legal& regulatory				X	X			X
Environment					X			
Technology		X		X	X		X	X
Priority		X						

4. Results

Structural self-interaction modelling (SSIM): The results of the literature review then develop the structural self-interaction matrix (SSIM), as shown in Table 2. According to the ISM methodology, the four symbols stated below were applied to represent the direction of relationships between two barriers (i and j):
V: Barrier i will influence barrier j, e.g., Barrier 1 (B1) will influence Barrier 3 (B3), thus the relationship is denoted as 'V' in the SSIM;
A: Barrier i will be influenced by barrier j, e.g., B1 will be influenced by B2, thus the relationship is denoted as 'A' in the SSIM;

X: Barrier i and j will influence each other, e.g., B1 and B12 will influence each other, thus the relationship is denoted as 'X' in the SSIM;
O: Barriers i and j are unrelated, e.g., there is no relationship between B1 and B9, thus the relationship is denoted as 'O' in the SSIM.

Table 2: Structural Self-Interaction Modelling

			J														
	Barriers	I	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1
1	Communication	B1	O	A	O	O	V	X	V	A	A	A	A	A	X	X	
2	Information	B2	O	V	V	O	V	X	V	A	O	V	A	X	X		
3	Awareness	B3	A	V	V	V	V	X	V	V	O	X	X	A			
4	Financial Support	B4	O	V	O	X	X	A	V	V	X	V	X				
5	Institutional involvement	B5	O	A	V	V	O	O	O	V	V	V					
6	skills	B6	A	A	O	O	A	A	A	A	A						
7	Market	B7	A	O	O	A	V	A	X	X							
8	Organizational	B8	A	X	V	A	A	X	X								
9	Behavioural	B9	V	X	V	O	V	A									
10	Economic	B10	X	O	V	O	V										
11	Cost	B11	V	A	V	O											
12	Legal& regulatory	B12	O	O	V												
13	Environment	B13	O	O													
14	Technology	B14	V														
15	priority	B15															

Reachability Matrix: After attaining the SSIM, it must be converted to an initial reachability matrix (binary matrix) using numbers 0 and 1. Therefore, the initial reachability matrix is developed based on SSIM and using the rules of substitution, as follows:

- If the cell (i, j) is determined by 'V' in the SSIM, the relevant cell in the matrix of the initial reachability would convert to number 1 and the cell (j, i) would convert to number 0.
- If the cell (i, j) is determined by 'A' in the SSIM, the relevant cell in the matrix of the initial reachability would convert to number 0 and the cell (j, i) would convert to number 1.
- If the cell (i, j) is determined by 'X' in the SSIM, both the cells (i, j) and (j, i) would convert to number 1 in the matrix of the initial reachability.
- If the cell (i, j) is determined by 'O' in the SSIM, both the cells (i, j) and (j, i) would convert to number 0 in the matrix of the initial reachability.

The final reachability can be referred to in Table 3- Final reachability matrix

Table 3: Final Reachability Matrix

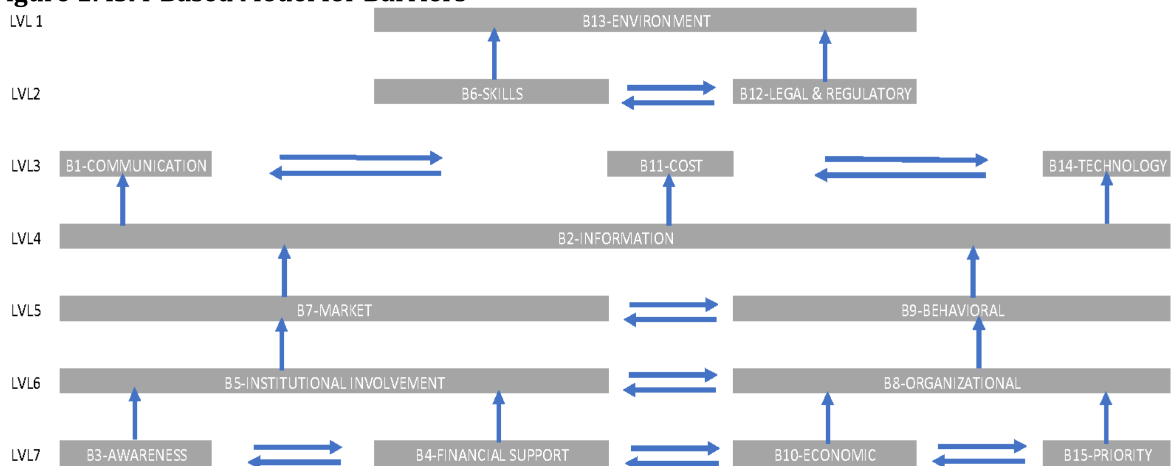
			J															
	Barriers	I	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	Driving Power
1	Communication	B1	1	0	0	0	1	1	1	0	0	0	0	0	1	1	0	6
2	Information	B2	0	1	1	0	1	1	1	0	0	1	0	0	1	0	0	7
3	Awareness	B3	1	1	1	0	1	1	1	1	0	1	1	0	0	1	1	11
4	Financial Support	B4	0	1	0	1	1	0	1	1	1	1	1	1	0	1	1	11
5	Institutional involvement	B5	0	0	1	1	0	0	0	1	1	1	1	1	1	1	0	9
6	skills	B6	1	0	0	0	0	0	0	0	0	0	1	1	1	1	0	5
7	Market	B7	1	0	0	0	1	0	1	1	1	0	1	1	1	0	0	8
8	Organizational	B8	1	1	1	0	0	1	1	1	0	0	1	1	1	0	0	9
9	Behavioural	B9	1	1	1	0	1	0	0	0	0	1	1	1	0	1	0	8
10	Economic	B10	1	0	1	0	1	1	1	1	1	1	1	1	0	1	0	11
11	Cost	B11	1	0	1	0	0	0	1	1	0	0	0	0	0	1	1	6
12	Legal& regulatory	B12	0	0	1	0	0	0	0	0	0	1	0	1	1	0	1	5
13	Environment	B13	0	0	1	0	0	1	0	0	1	0	1	0	0	0	0	4
14	Technology	B14	1	0	1	0	0	1	0	0	1	0	1	0	0	0	1	6
15	priority	B15	1	0	1	1	1	1	0	0	1	1	1	1	1	1	0	11
	Dependence Power		10	5	11	3	8	8	8	7	7	8	11	9	8	9	5	

Level Partition and ISM Base Model: From Table 3- Final reachability matrix, the reachability set composes the barriers themselves and other barriers that it may influence. In contrast, the antecedent set comprises the barriers and the other barriers that may influence it. Subsequently, these sets' intersections are required to verify all the barriers and levels of different barriers. The barriers with the same reachability and the intersection sets occupy the top level in the ISM hierarchy. The top-level barriers are those barriers that will not lead the other barriers above their level in the hierarchy. Once the top-level barrier is recognized, it will be removed from consideration. Then, the same process will be repeated to identify the barriers to the following level. This process is continued until the level of each barrier is obtained. Table 4: level partition shows the 15 barriers and their reachability sets, antecedent sets, intersection sets, and levels. The level identification process of these barriers is completed in eight iterations. As illustrated in Table 4: level partition and the relationship of the barriers can be referred to as per Figure 1-ISM-based model for barriers.

Table 4: Level Partition

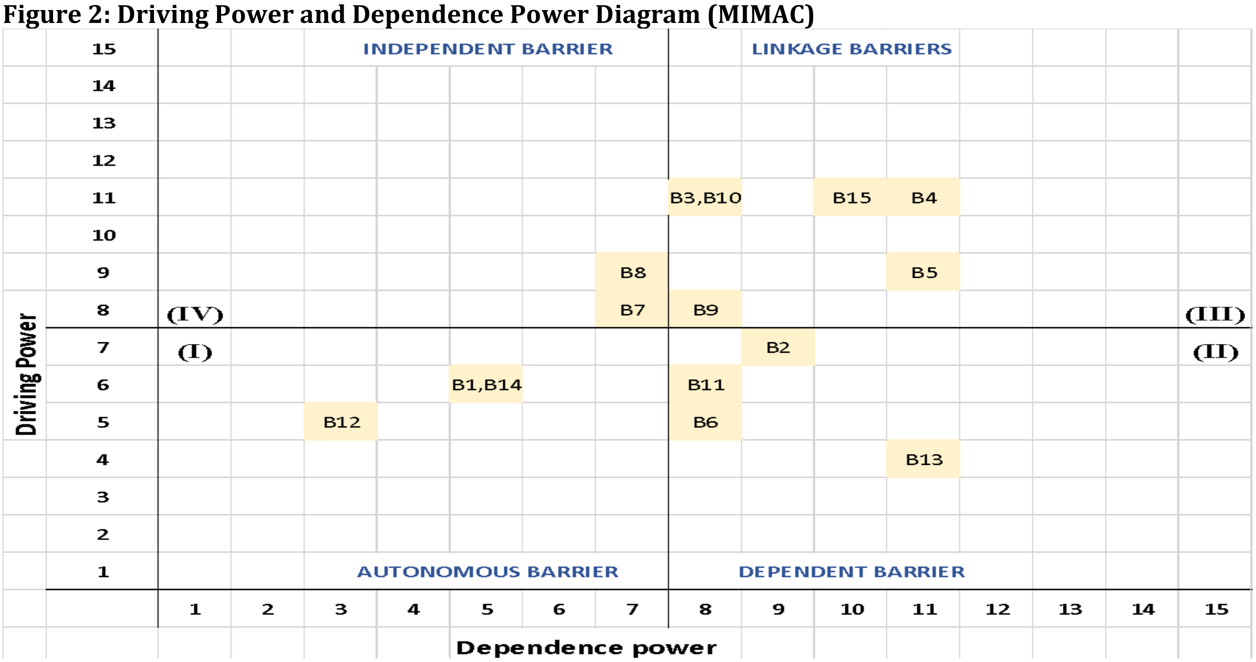
Barriers	Reachability set	Antecedent set	Intersection set	levels
B13	13	B2,B3,B4,B8,B9,B10,B11,B12,B13,B14,B15	13	I
B6	6,12	B2,B3,B4,B5,B9,B10,B12,B15	6,12	II
B12	6,12	B4,B5,B15	6,12	II
B1	1,11,14	B3,B4,B11,B12,B14	1,11,14	III
B11	1,11,14	B1,B2,B3,B4,B7,B9,B10,B15	1,11,14	III
B14	1,11,14	B2,B3,B4,B8,B9	1,11,14	III
B2	2	B1,B3,B4,B5,B6,B9,B10,B11,B15	2	IV
B7	7,9,	B4,B5,B7,B10,B13,B14,B15	7,9,	V
B9	7,9	B1,B2,B3,B4,B7,B10,B11,	7,9	V
B5	5,8	B3,B4,B5,B6,B7,B8,B9,10,B13,B14,B15	5,8	VI
B8	5,8	B3,B4,B5,B7,B8,B10,B11,	5,8	VI
B3	3,4,10,15	B1,B2,B5,B6,B7,B8,B12,B15	3,4,10,15	VII
B4	3,4,10,15	B4,B5,B6,B7,B8,B9,B10,B12,B15	3,4,10,15	VII
B10	3,4,10,15	B1,B2,B3,B8,B10,B13,B14,B15	3,4,10,15	VII
B15	3,4,10,15	B1,B3,B6,B7,B8,B9,B10,B11,B14,B15	3,4,10,15	VII

Figure 1: ISM-Based Model for Barriers



MICMAC Analysis Graph: MICMAC is the abbreviation for 'Matriced Impacts Croises-Multiplication Applique and Classement' (Cross-Impact Matrix Multiplication Applied to Classification), developed from the multiplication properties of matrices. Godet initially introduced MICMAC analysis in 1986 to examine the driving power and dependence of enablers. This analysis is to distinguish the main enablers that drive the model in a variety of classes. The driving power and dependable power for each barrier are tabulated in the MICMAC table, obtained from the final reachability matrix by summation of rows to analyze driving power and summation of columns to study dependency power as per Figure 2 Driving power and dependence power diagram (MIMAC).

Figure 2: Driving Power and Dependence Power Diagram (MIMAC)



Autonomous Barriers, Quadrant I: This quadrant does not have much influence on the model; therefore, if the barriers are in this area then they will be virtually isolated since they are relatively disconnected from the model. The barriers under autonomous quadrant I that do not influence other barriers are B1, B12 and B14.

Dependent Barriers, Quadrant II: This quadrant contains barriers that have weak driving power but strong dependence power. The barriers under dependent quadrant II have weak driving power, but strong dependence power the barriers are B2, B6, B11 and B13.

Quadrant III: This quadrant contains linkage barriers that have both strong driving and dependence powers. They are also considered unstable whereby any action on them will have an impact on other barriers as well as themselves. The barriers under linkage quadrant III with strong driving power and dependence power are B3, B4, B5, B9, B10, and B15.

Independent barriers, Quadrant IV: This quadrant shows the independent barriers, involving those that have strong driving power and weak dependence power. These barriers under independent quadrant IV have strong driving power, but weak dependence powers are B7 and B8. Barriers to market and organization.

Discussion: Based on the MIMAC diagram, there are two barriers positioned within the independent quadrant. The two barriers are B8-Organisation and B7-Market. The organizational commitment barrier positioned in the MIMAC diagram shows that it is slightly below the mid-point of the dependence scale and above the mid-point for driving power. It shows that the organization's barrier has less dependency on other barriers, and at the same time, it has higher driving power compared to other barriers. Market availability is also positioned in the independent quadrant below the mid-point of the dependence scale and slightly above the driving power scale.

Based on the MIMAC diagram, two barriers have the highest driving force and one point higher the dependence power but are located just within the linkage quadrant. There are two barriers, namely B3-awareness and B10-Economy. The position of these two barriers compared to the market and organization; these two barriers seems more dominant and influence other barriers.

Comparing the MIMAC analysis and ISM analysis, the B8-organisation barrier committed in the ISM model has a dependency on level 7 barriers such as B10-Economy and B15-Priority. B8- The organizational barrier also has a mutual dependency on B5-Institutional involvement. The B7-Market has a dependency on the level 6 barrier, which is the B5-Institutional involvement barrier. The B7-Market has a mutual dependency on the B9-Behaviour barrier. The ISM model also observed that B5-Institutional involvement is the dependent barrier for both the B8-Organisation and B7-Market. The ISM model also shows that the dependency of B7-Market is dependent on barrier B8- Organization, which must go through another dependency from the B9-Behavioral barrier.

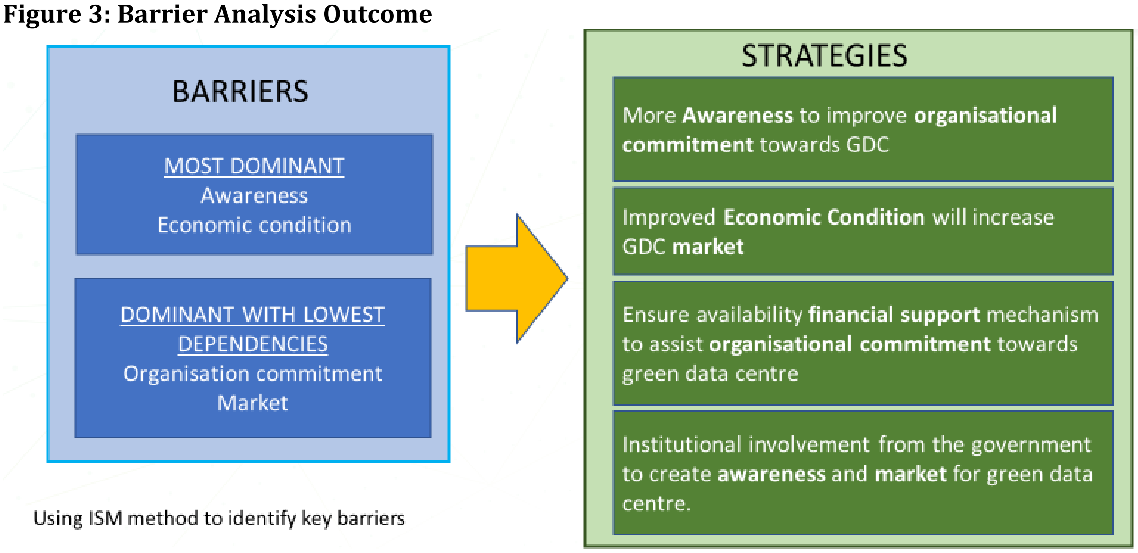
Based on the MIMAC diagram, there are two barriers positioned within the independent quadrant. The two barriers are B8-Organisation and B7-Market. The organizational commitment barrier positioned in the

- Awareness amongst industry actors is the most dominant barrier—more awareness programs are needed for all the actors in the green data center. The government plays a significant role in providing institutional support and creating awareness amongst the actors.
- The nation's economic climate is the driving force for both the private and public sectors in promoting green data center initiatives.
- To minimize the organizational barrier towards green data centers, organizations must prioritize commitment to sustainable energy programs or energy efficiency programs.
- The economic condition also influences organizational commitment to the green data center. If the economic condition is good, the organization will be willing to commit to a green data center.
- Awareness of green data centers can also influence organizational commitment, thus more awareness programs by the government to support this program.
- An organizational commitment to green data center initiatives is also influenced by the financial support available, especially from financial institutions.
- To have more institutional involvement, especially from government agencies to create markets for the green data center. Maybe this initiative should start at the government premises as a showcase to the market.
- In supporting the market for green data centers, organizational behavior also plays a mutual role between them. Thus, an awareness program is essential to improve organizational behavior towards energy conservation.
- There is an indirect relationship between market and organizational commitment—the relationship

between market and organizational commitment moderated by behavior. Similarly, the relationship between market and organizational commitment can be moderated by institutional involvement.

In summary, the barrier analysis outcome and summarized strategy are as per Figure 3: Barrier analysis outcome.

Figure 3: Barrier Analysis Outcome



5. Managerial Implications and Recommendations

The data center market is set to grow by 7% during 2022-2027, expected to reach RM2.0 billion by 2027. It will be an overwhelming success for the Malaysian ICT industry in which I could provide better FDI opportunities which could lead to more ICT and Green jobs. Based on this study, government incentives provide a catalyst for transforming a traditional data center into a green data center. More studies could be explored in the implementation of green data technologies which will be more cost effective in focusing on the Malaysian data centers. In addition, awareness of current government incentives could further be explored to benefit the ICT industry more to switch to more green ICT operations in Malaysia.

Conclusion: The primary barriers to green data center implementation in Malaysia are the awareness of the green data center and the economic conditions of the country. Improving awareness of green data centers on their impact on the environment. The green data center implementation will require additional costs. These additional costs will be transferred to the consumers. But, with the importance of managing big data nowadays, the government has to step in various ways to support the implementation of the green data center, such as providing some incentives in terms of tax rebates which have been introduced for other green and renewable energy projects. Providing interest rate rebates for green data centers could also spur more interest from the operators. The future of green data centers is here to go for the future. The government, with a focus on supporting climate change mitigation actions, has to initiate more innovative financial incentives either directly or indirectly through financial institutions. Grants are being issued by the government for conducting energy audit buildings in Malaysia, and a similar concept could be introduced for green data center implementation to acquire energy-efficient equipment. Further study is required in the economic and financial aspects of the implementation of a green data center.

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