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An Indicator Framework Approach on Manufacturing Water Assessment towards Sustainable Water Demand Management

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Abstract

Population growth, industrialization, urbanization and change of life style have increased global water demand. Although agricultural water demand accounts as the largest overall user, emerging economics causes industrial and domestic water demand to increase tremendously especially in developing countries. One sector that contributes to rapid industrial demand is manufacturing sector. Despite many assessment methods being used in the past, it has been seen that measurement of manufacturing water use performance could only be done for specific manufacturing factory or specific industries. Due to lack of a holistic framework towards assessment water performance in any given manufacturing factory, this paper introduces an indicator-framework called Malaysia Manufacturing Industry Water Benchmarking System (MIWABS). This indicator framework was developed based on relevant sets of indicators arranged under sustainability pillars criteria. MIWABS uses stakeholder-driven approach whereby the established indicators and Analytic Hierarchy Process (AHP) assigning weightage were done through workshops and questionnaires. Rubber glove and semiconductor industries were chosen as demonstration study to validate the indicator-framework. The results highlighted the importance to emphasize on recycling water in manufacturing facilities. Besides that, manufacturing factories shall also explore other water alternatives such as groundwater and river to cater for their factory and production needs to reduce the dependency of potable water by public water operator. It is hoped that MIWABS can give input and policy direction as part of water demand management strategies in Malaysia.

Keywords: Manufacturing water use, Water demand management, Indicator-framework, Sustainability

1 Introduction

1.1 Background

Nowadays, sustainable water resource management is an overall concern in the world. With increasing population and urbanization expansion, the world will face a severe global water deficit (1) if water demand continues to rise with the finite water supply. Unavoidably, population increase will have direct impact to meet the demand in all sectors including domestic, agricultural and industrial sector (2). Growing water demand of 55% is projected by 2050. Among all sectors, an increase of 400% for manufacturing water demand is expected from 2000 to 2050. Multiple approaches have been used in assessing manufacturing water use. In those separate studies, indicators such as water per product, recycling rate and wastewater generation had been evaluated for optimization. These indicators are arranged according to sustainability pillar criteria as shown in Table 1.

Focusing within a manufacturing facility, common water use is for the manufacturing process such as fabricating, cleaning, cooling, transporting a product, embedded as final product, cooling system, water treatment plant and also for drinking and sanitation (3). Industrialization does play an important role in boosting development in economy (4). In low- and middle-income countries, industrial water demand is about 10%, however, this percentage is significantly different for high GDP countries where industrial water takes up about 60% of the total water demand. Therefore, since water resources are shared among sectors, assessment of water use in manufacturing sector is important. For example in China, economic transformation tremendously has changed the water demand proportion (5). The shift of water demand causes more initiatives to be introduced such as the Three Red Lines to control water use (6). All previous research had been carried out to optimize and minimize water use in primary activities such as process water and cooling water. Besides that, they also investigated minimization of wastewater generation that can be harmful to the environment. These approaches used indicators or drivers that reflect the current condition and helped to monitor for future trend as well. However, these indicators have yet to be presented in a holistic way to assess the performance of manufacturing water use. Thus, this paper aims to introduce the development of indicator-framework for manufacturing

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water use called, Malaysia Manufacturing Industry Water Benchmarking System (MIWABS). This indicator framework has been developed through collaboration between Universiti Teknologi Malaysia (UTM) and National Water Service Commission (SPAN).

Table 1: Indicators for manufacturing water use in previous researches

Sustainability Aspect	Indicators	Reference
Economic	Manufacturing gross value added GDP / freshwater use Shadow price of freshwater Shadow price of wastewater GDP per capita Payback period Water treatment cost	(7–11)
Environment	Recycled water ratio Water use per unit output Water recirculation rate Total water intake Savings in water consumption Specific water-cooling demand per product Process water consumption Groundwater withdrawal pH Water depletion Embodied water in coal use embodied water in oil use embodied water in other use BOD5 COD Total dissolved solids (TDS) Suspended Solid Total nitrogen Dissolved Oxygen Total phosphorus Total iron Reduction of wastewater generation Temperature	(9,10,12–32)
Social	Training Inefficiency level of execution of ISO 14000	(18,20,33)

Section 2 will explain on the concept of indicator-framework and examples of indicator-framework that had been developed in water resources management previously. Then, in Section 3, the detail methodology for the development of MIWABS will be explained. Section 4 shows the discussion of the results. Conclusion and recommendation for future work are then portrayed in Section 5 and Section 6, respectively.

2 The Concept of Indicator-Framework

One of the established methods to assess the performance of water use is by using indicator-framework. It consists of indicators, aspect and indices (34). An index which is a single score number is obtained when aggregation of indicators is made based on some standardized manner. Selection of indicators shall be done according to these criteria (35): relevant, quantifiable, accessible, timely manner, and long term oriented.

The measurement of indices is made from time to time that allows tracking of trends and improvement. Changes of the multidisciplinary indicators can also be made based on applicability during time of measurements. Understanding these trends allow stakeholders to make concise decision for future betterment. Table 2 shows the example of developed indicator framework in water resources management. Indicator framework has been utilized to assess urban water, river basin, region and country water demand. Juwana et al. (2016) had developed WJWSI for river basin in Indonesia. Result for WJWSI gives comparison for the catchments used as a starting point by water authorities to embark on direction of water demand management of the said area. Water Poverty Index on the other hand, indicates water situation based on multidisciplinary indicators including physical and socioeconomics aspects.

The index allows countries and communities to be ranked and it also enables the national and international organisations to take necessary action on the resources available. Furthermore, the impact towards the resources and its use can be assessed by both organisations based on the socio-economic factors. Studies have shown that indicator framework can produce a conclusive assessment to deliver overall current and performance improvement.

3 Research Flow

The development of MIWABS consists of six (6) steps as shown in Figure 1. As the scope was defined, the aspect of research was identified. Horizon scanning of possible indicators was carried out. Then, these indicators were screened and filtered through workshop attended by relevant stakeholders. After that, based on established aspects and indicators, data collection took place in order to demonstrate the indicator-framework. Next, normalization of data was done where Proximity-to-Target method was used. Weightage assignment was carried out by using AHP method and questionnaire was distributed to water experts in Malaysia. Lastly, the aggregation of MIWABS indicators was done to express the performance of manufacturing factories in term of score.

• **Stage one — Horizon scanning:** The criteria for the sustainable indicators relevant to manufacturing water demand was based on sustainability concepts which are environmental, economic, technological, and societal. These are the common aspects when it comes to sustainability. In order to establish the indicators, horizon scanning of existing indicators with respect to manufacturing water demand was done. Along with the criteria set, sustainable indicators must be measurable and relevant to be applied generically in all manufacturing industries in Malaysia.

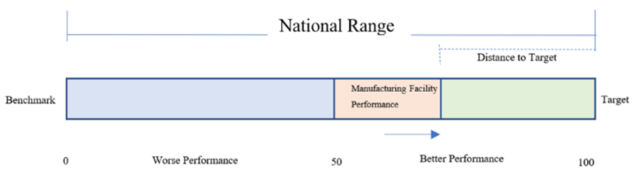

Figure 1: Research flow for development of MIWABS

Table 2: Indicator-framework in water demand management

Author	Indicator Framework	Aspect	Number of indicators	Scope
(37)	Water Poverty Index (WPI)	• Time taken to collect domestic water • Clean sanitation • Water Availability • Access to safe water	3	Region or country
(38)	Watershed Sustainability Index (WSI)	• Life • Environment • Hydrology • Policy	5	River Basin
(39)	Canadian Water Sustainability Index (CWSI)	• Resource • Ecosystem Health • Infrastructure • Human Health and Well Being • Community Capacity	15	Canada
(40)	Sustainable Cities Water Index (SCWI)	• Resiliency • Quality • Efficiency	20	50 Cities in the world
(36)	West Java Water Sustainability Index (WJWSI)	• Conservation • Water use • Policy and Governance	9	River Basin

• **Stage two — Stakeholders' perception for filtration of indicators:** Based on the possible indicators gathered from the horizon scanning process, filtration of indicators had been carried out through a working session with water and manufacturing stakeholders. Stakeholders consist of representatives from SPAN, water operators, government agencies, private agencies, and manufacturing factories. Thorough discussion among the stakeholders had managed to identify and establish the sets of indicators that was utilised for MIWABS.

• **Stage three — Data collection through questionnaires for manufacturing factories:** Based on the established sustainable indicators, a questionnaire was developed and distributed to selected manufacturing industries. As a pilot study, scoping for water intensive manufacturing industry was based on manufacturing census 2015 that was carried out by the Department of Statistics Malaysia. Two manufacturing sectors had been selected for the development of MIWABS namely rubber glove and semiconductor manufacturing factories.

• **Stage four — Normalization of indicators:** The measurement units for the established indicators were different. Thus, statistical normalization of raw data was needed before a weightage can be assigned for each indicator (OECD, 2008). Proximity-to-Target (PTT) method was chosen to normalize the data indicators. The concept of this method is illustrated in Figure 2 and equations for 1 and 2 are stated as well. Based on the type of indicator, formula to calculate the PTT score is given as follows:

Equation 1:

$$\text{PTT Type A} = [(\text{Target} - \text{Minimum}) - (\text{Target} - \text{Data})] \times 100 / (\text{Target} - \text{Minimum})$$

Equation 2:

$$\text{PTT Type B} = [(\text{Maximum} - \text{Target}) - (\text{Data} - \text{Target})] \times 100 / (\text{Maximum} - \text{Target})$$

• **Stage five —Weightage Assignment:** Analytical Hierarchy Process (AHP) by Saaty in 1980 was adopted to assign weightage. This method is widely used in the world to support individual and group decision making. Basically, the method uses problem modelling, weights valuation, weights aggregation and sensitivity analysis to rank the aspects (41). The AHP questionnaire was designed and distributed to water experts in Malaysia.

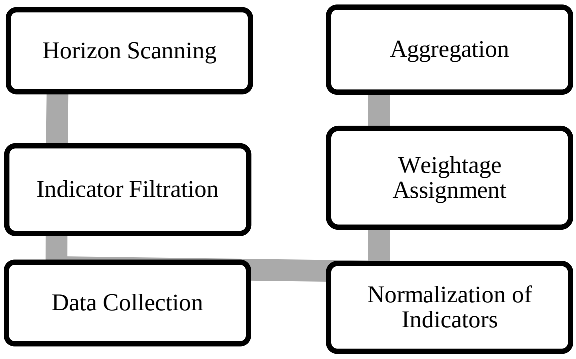

Figure 2: Proximity-to-Target concept

• **Stage six — Aggregation of Indicators:**

MIWABS total score was calculated based on aggregation of the assigned aspect weightage and each indicator score. Based on the rating system as shown in Table 3, MIWABS score were categorised into four (4) categories of performance which are poor, fair, good, and excellent.

Table 3: Distribution of PTT Score, Star Rating, Colour Code and Performance.

MIWABS Score (%)	Rating		Performance
75 ≤ x ≤ 100	4		Excellent
50 ≤ x ≤ 74	3		Good
25 ≤ x ≤ 49	2		Fair
0 ≤ x ≤ 24	1		Poor

4 Result

4.1 The MIWABS Indicator Framework

The framework structure to develop MIWABS is as shown in Figure 3. The total score for MIWABS is reflected on the total score for all four criteria (economic, environmental, social and technical). The total score for each aspect depends on the score of each indicator. This hierarchy system is the key system to develop the score (42). As a result, a total of nine (9) indicators under four (4) aspects with readily available data was produced through the outcomes of the workshop which are deemed suitable to be implemented and to be used by the manufacturing factories in Malaysia. The established four (4) aspects for MIWABS are from sustainability pillars and one additional criterion was added to suit the manufacturing sector. Besides that, the MIWABS framework also considers the Sustainable Development Goal (SDG) initiatives before indicators were screened and selected. Based on these, four criteria are used for MIWABS framework which are: economic, environmental, social, and technical.

4.2 Normalized Indicators Values

Normalization of data was carried out by using PTT score as shown in Figure 4. In order to develop the framework indicator, target and low benchmark were another crucial step to be included. These values were established based on their nature with different unit of measurements. The first preference was to set the target and low benchmark based on the policy statement made by the Malaysian government. Then, next resources on literature review in Malaysia or international level were used. Lastly, the best and the worst performance of the indicator based on the collected data were used as reference. Besides that, since there were two (2) pilot manufacturing industries selected for MIWABS, low benchmark and target were also established based on each industry to cater for the different natures of water use in those manufacturing productions. Discussions had been done with DOSM and manufacturing factory personnel to establish the target and benchmark of these indicators. For economic aspect, two (2) indicators were evaluated which are the percentage of water in product in terms of cost and industrial wastewater cost. The first indicator in this aspect is the percentage of water in product in terms of cost whereby benchmarking from the Department of Statistics Malaysia was used. For rubber glove manufacturing, except for Factory 2, most of the factories scored between 80% and 100%. On the other hand, the range of PTT score for E1 in semiconductor industry is between 60% and 100%. Questionnaire feedback shows that only 6 factories recycle their water. In comparison between manufacturing sector, semiconductor industry recycles more of their water as compared to rubber glove manufacturing. The recycle water comes from the cooling system. As for water per product and wastewater per product, semiconductor shows more uniform result.

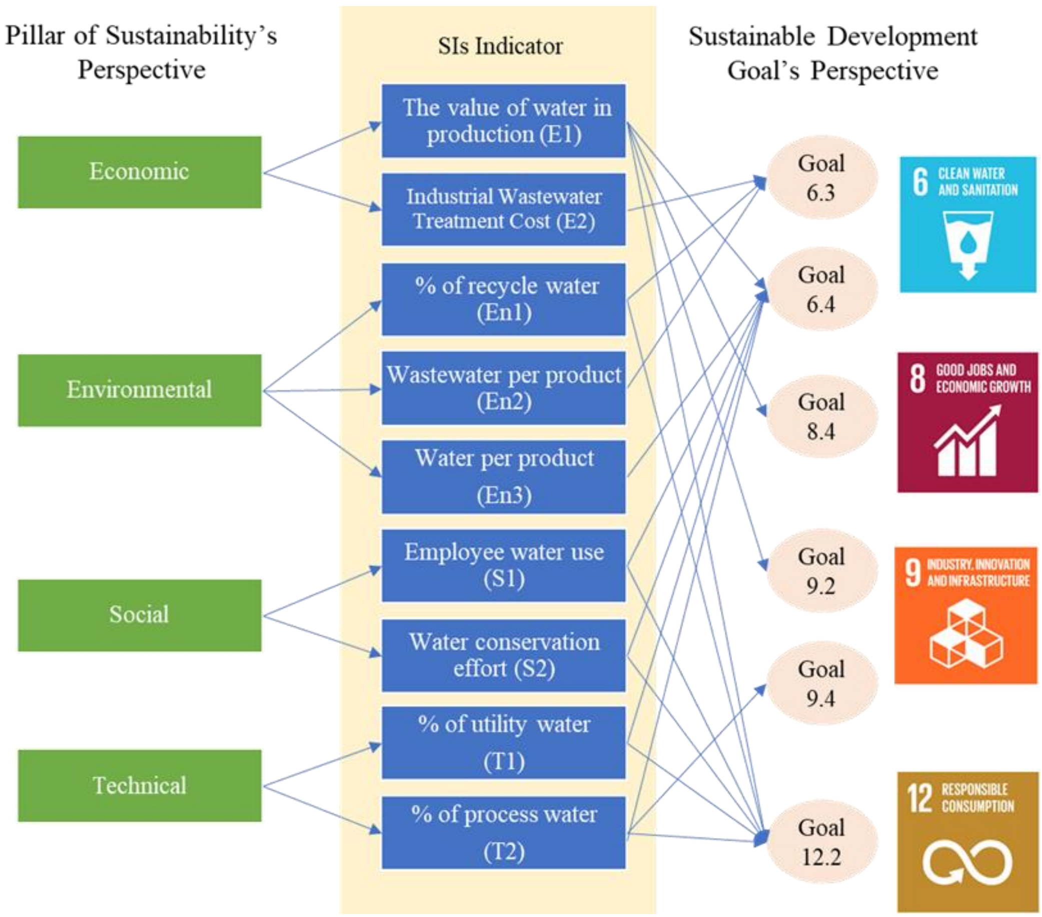

Figure 3: MIWABS framework

Table 4: MIWABS Established Indicators and Its Description

Aspect	SDG	Code	Indicator	Unit	Description
Economic	8.4, 12.2	E1	% of water in product in terms of cost	(RM/RM)	The annual cost paid to purchase water over annual sales of product.
	6.3	E2	Industrial Wastewater Treatment Cost	Cost (RM) / wastewater (m^3)	The annual operational cost for wastewater treatment plant over annual amount of industrial wastewater generated.
Environment	6.3, 12.2	En1	% of recycle water	%	The percentage of annual amount of recycle water over annual amount of water intake within the factory.
	6.3	En2	Wastewater per product	m^3/ product	The total amount of wastewater generated to manufacture a product.
	6.4	En3	Water per product	m^3/ product	The total amount water used to manufacture a product.
Social	6.4, 12.2	S1	Employee water use	m^3/employee/ day	The total amount of daily water use per employee.
	6.4, 12.2	S2	Water conservation effort	%	The level of water conservation effort and monitoring carried out within the facility.
Technical	6.4, 12.2	T1	% of utility water	%	The percentage of annual amount of utility water over annual amount of water intake within the factory.
	8.4, 9.4, 12.2	T2	% of process water	%	The total percentage of annual amount of water used for process over annual amount of water intake within the factory.

This may be contributed since most semiconductor factories in Malaysia are following the international standards from their parent company oversea. Result from employee water use shows higher and more consistent PTT score for semiconductor industry as compared to rubber glove manufacturing. As for water conservation effort, the average for rubber glove manufacturing is 65%, whereas the PPT score for water conservation in semiconductor manufacturing is 81%. As for technical aspect, rubber glove factories have put initiative to look for other alternative water resources such as groundwater and river. On the other hand, result shows that semiconductor industry is fully dependent on potable water intake from public utility operator. PTT score for percentage of process water in semiconductor manufacturing shows more consistent result among factories as compared to rubber glove manufacturing.

4.3 Weightage Assignment

Based on the result, the Consistency Ratio (CR) produced was 0.001006, which is lower than 0.1 as acceptable (43). With Random Index (RI) of 0.9, the Consistency Index (CI) was 0.00091. The eigenvector matrix was found to be 0.2961, 0.3862, 0.1621 and 0.1556. The sum of these eigenvector values was one (1). These eigenvector values were then used as weightage in this study. The priority weight for C1, C2, C3 and C4 were 29.6%, 38.6%, 16.2% and 15.6% respectively.

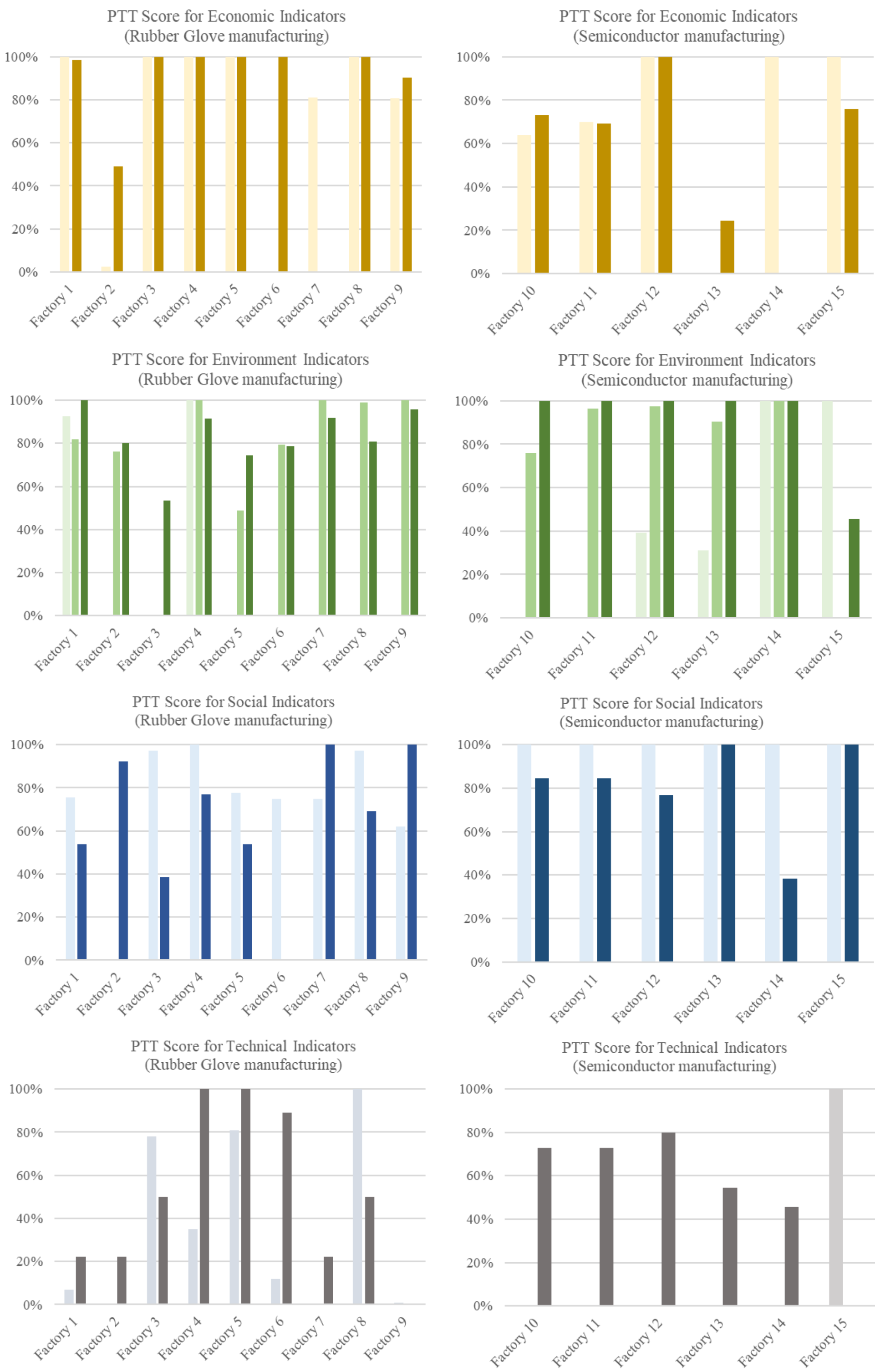

Figure 4: PTT Score for MIWABS Indicators

This means that, environmental indicator is the most important, which is then followed by economic indicator, social indicator and lastly, technical indicator. The weight value of each criterion in this study is summarised in Table 5. The AHP results show that, water experts put more concern on environmental aspect of manufacturing water use. This is indeed relevant as the indicators relate directly to water minimization and wastewater generation. In states such as Selangor, Johor and Pulau Pinang where the manufacturing industries are highly populated, non-domestic water takes up about 50% of their water consumption. This also leads to huge amount of wastewater. Without proper treatment, contamination to river may occur. Then, economic aspect of manufacturing water use is weighted as second important among the aspects. Even though the water tariff for manufacturing is higher from the domestic user, concern of water operation to supply treated water in Malaysia is considerably low and not optimum at this moment. Coming in third is the social aspect which covers the behaviour of employee water use as well as water conservation effort in manufacturing water use.

Table 5: Weight Value of Each criterion

Code	Aspect	Weight Value (%)	Relative Importance
C1	Economic Indicator	29.6%	2
C2	Environmental Indicator	38.6%	1
C3	Social Indicator	16.2%	3
C4	Technical Indicator	15.6%	4

Employee water use has less significant impact on total water use in manufacturing. Lastly, technical aspect which covers source of water for manufacturing water use and technology efficiency of process activity is put as the last ranking. To date, no demarcation of water source point for manufacturing factory has been in place. In short, the results obtained from the AHP analysis are reasonable and thus accepted as they demonstrated the real scenario in Malaysia. The obtained results are further discussed, validated, and concurred by SPAN.

4.4 MIWABS Score

Based on this indicator framework, data were collected based on 2 pilot manufacturing industries which are rubber glove and semiconductor manufacturing factories. The result for MIWABS score for all manufacturing factories are shown in Figure 5. For semiconductor industry (Factory 10 to Factory 15), the scoring is more uniform as compared to rubber glove manufacturing (Factory 1 to Factory 9). The score for rubber glove manufacturing is from 37% to 92%, whereas the score for semiconductor manufacturing is from 53% to 81%. This may be contributed by those manufacturing factories that follow the same practices as their parent international company overseas. On the other hand, rubber glove manufacturing is mostly Malaysian companies. Based on the feedback from the questionnaires, water usage within the factories in the rubber glove manufacturing varies from one another in terms of water per product, wastewater per product and employee water use.

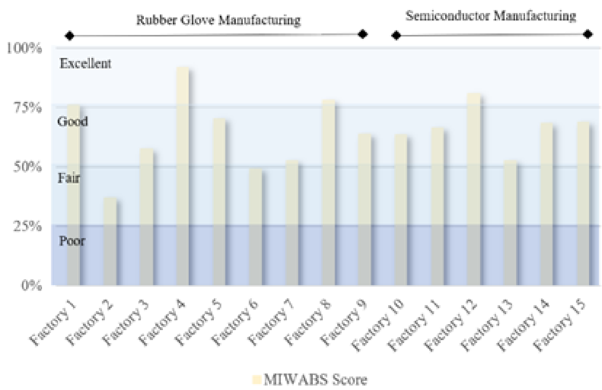

Figure 5: MIWABS Score

5 Discussion

To date, there is no policy or specific guideline on water use in manufacturing factories in Malaysia. Through the observation from questionnaires and interviews feedback from manufacturing personnel, water use in factory has not been the primary parameter for conservation or optimization as compared to energy or other resources for production. As agreed, the tariff has not been of any issue and water has yet been treated as a precious commodity in the manufacturing production. However, the interruption in water supply is more of their concern. Looking at the aggregation of nine MIWABS indicators (Figure 6), it shows that, improvement can be made in manufacturing factories based on the total percentage of recycling water (En1) and percentage of utility water in factory (T1). As mentioned in the water demand management strategies, it is suggested for water recycling in the manufacturing sector to be up to 30% (ASM, 2016). Recycling water can help to minimize water intake as it can be reused for suitable manufacturing activities. Therefore, support and comprehensive policy direction on recycling water in manufacturing sector should be introduced.

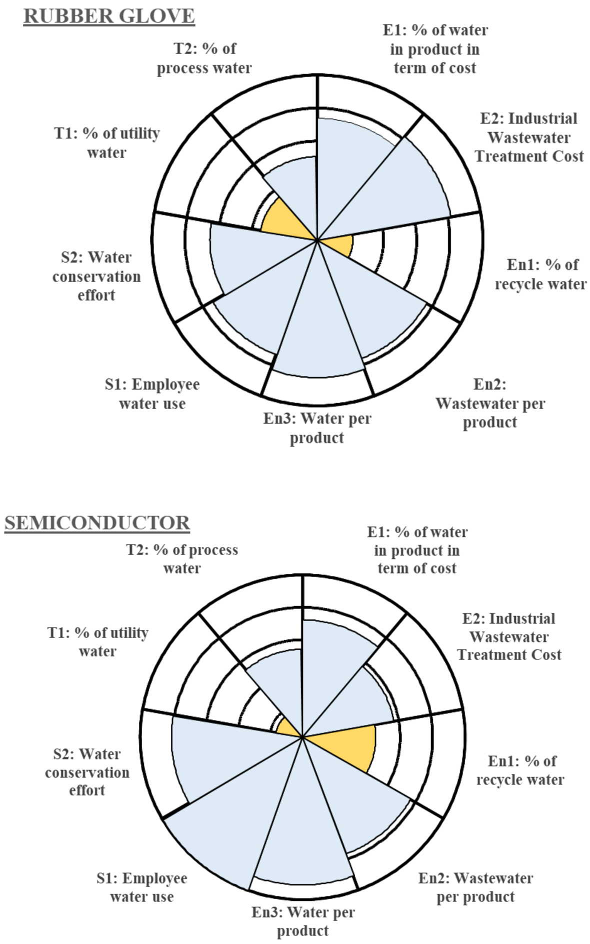

Figure 6: Pie Radar Chart for Malaysia Rubber Glove and Semiconductor Manufacturing Industry

Secondly, manufacturing industry shall reduce their dependency on potable water supplied by the water utility company. This can help to reduce the competitiveness of shared potable water with commercial and domestic sectors. Besides that, it gives lower change of water interruption that can affect production. This initiative had been carried out by one of the rubber glove manufacturing factories where water intake is 100% coming from the river. By setting up their own water treatment plant, the cost to purchase water is much lower than utilising potable water from the water operator. Few factories have also opted taking up water from groundwater which helps to reduce potable water intake. By improving these indicators in manufacturing water use, more effective water demand management in Malaysia can be achieved. Moreover, it will support the action plan in line with the Sustainable Development Goal as follows:

Table 6: The action plan in line with the Sustainable Development Goal

SDG	Description
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.
9.4	By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries acting in accordance with their respective capabilities.
12.2	By 2030, achieve the sustainable management and efficient use of natural resources.

6 Conclusion

This paper introduces an indicator-framework called MIWABS to assess the performance of manufacturing water use. Through MIWABS, significant improvement towards water demand management for Malaysia can be aimed as follows:

- Important indicators for manufacturing water use for any industry had been established.
- Important aspects in manufacturing water use had been identified. More effort in environmental element for manufacturing water use shall be made to reduce water use per product and wastewater per product.
- By monitoring the performance of indicators to its target, MIWABS enables water stakeholders and manufacturing sector to determine focus area such as percentage of water recycling for improvement towards more effective manufacturing water demand.
- More effort can be done to explore for alternative water resource other than potable water for manufacturing.

Besides that, this indicator framework can be adopted by any manufacturing factory elsewhere. By customization of sets of indicators, benchmark and target, this indicator framework can measure the performance of manufacturing water use at all level (between factories, states, or national level). As a result, the MIWABS framework can simplify the complex nature of manufacturing water use to a form that is relatively easy to communicate to the stakeholders. By using this indicator framework, a more holistic approach can be achieved towards sustainable manufacturing water demand.

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Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

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