NASF/AESF Foundation Research Reports

Project R-121 Q13

13th Quarterly Report
April-June 2023
AESF Research Project #R-121

Development of a Sustainability Metrics System and a Technical Solution Method for Sustainable Metal Finishing

by
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Editor's Note: *This NASF-AESF Foundation research project report covers the 13th quarter of project work (April-June 2023) at Wayne State University in Detroit, Michigan.*

Overview

It is widely recognized in many industries that sustainability is a key driver of innovation. Numerous companies, especially large ones who made sustainability as a goal, are achieving clearly more competitive advantages. The metal finishing industry, however, is clearly behind others in response to the challenging needs for sustainable development.

This research project aims to:

1. Create a metal-finishing-specific sustainability metrics system, which will contain sets of indicators for measuring economic, environmental and social sustainability,
2. Develop a general and effective method for systematic sustainability assessment of any metal finishing facility that could have multiple production lines, and for estimating the capacities of technologies for sustainability performance improvement,
3. Develop a sustainability-oriented strategy analysis method that can be used to analyze sustainability assessment results, identify and rank weaknesses in the economic, environmental, and social categories, and then evaluate technical options for performance improvement and profitability assurance in plants, and
4. Introduce the sustainability metrics system and methods for sustainability assessment and strategic analysis to the industry.

This will help metal finishing facilities to conduct a self-managed sustainability assessment as well as identify technical solutions for sustainability performance improvement.

Progress Report (Quarter 13)

1. Student participation

Abdurrafay Siddiqui and Mahboubeh Moghadasi, two Ph.D. students in the Principal Investigator's (P.I.) group, conducted research in this reporting period. .They are financially supported mainly by Wayne State University's Graduate Teaching Assistantship Program, and partially by National Science Foundation and this AESF research project.

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In addition, Ryan Kitelinger, an undergraduate student of chemical engineering at Florida Institute of Technology, was hired for one of the P.I.'s other NSF grants, which supports him to conduct a 10-week research program in the P.I.'s lab during the Summer Academy of Sustainable Manufacturing at Wayne State University, which started on June 1, 2023.

2. Summary of project activities

Under the P.I.'s supervision, the student research activities are summarized below:

Abdurrafay Siddiqui continued to develop a computer-aided tool, namely the ISAE (Industrial Sustainability Assessment and Enhancement) tool. Earlier work in the development of the ISAE was reported in the 7th, 8th, 9th and 11th quarterly reports. In this reporting period, Abdurrafay implemented a technology assessment and selection methodology and tested it through a case study.

Mahboubeh Moghadasi focused on the development of a set of digital twins (DTs) using the physics-informed neural network (PINN) technology. She has been making impressive progress in learning PINN fundamentals, writing computer codes using Python – a high-level, general-purpose programming language, and simulating a PINN-based cleaning-rinsing system model set. We intend to make the PINN model much more robust than the fundamental models we developed before, as the PINN model will have its key model parameters continuously updated based on real-time dynamic data.

Ryan Kitelinger studied the fundamentals of electroplating and engineering sustainability through a literature survey and conducted a computer simulation of a cleaning-rinsing model set. He presented his work during the PI's lab group meetings and the Summer Academy at Wayne State weekly. The student has shown his strong interest in electroplating and his ability of using chemical engineering fundamentals to study electroplating sustainability problems, including how to identify opportunities for reducing chemical and water consumption, while the cleaning and rinsing quality can be guaranteed.

Regarding conference attendance and presentations, the PI and his two Ph.D. students attended the SUR/FIN Conference in Cleveland, OH on June 6, 2023. We presented the following two papers: (1) A. Siddiqui and Y. Huang, "Industrial Sustainability Assessment and Enhancement (ISAE) Tool" and (2) M/ Moghadasi and Y. Huang, "Digital Twin-Based Dynamic Sustainability Assessment of Electroplating Facilities." The two students discussed their research with industrial practitioners during the conference, which was very beneficial to them.

Both Ph.D. students submitted their individual research progress reports to the P.I., one on the ISAE tool development and a case study (13 pages), and the other on PINN development (18 pages). However, the P.I. decided only to report the ISAE tool development and case study in this report. The PINN study will be reported in the next quarterly report, which will contain more research results in the following months.

3. ISAE tool development and case study

We have continued to enhance the computer-aided Industrial Sustainability Assessment and Enhancement (ISAE) tool. In this reporting period, we further enhanced the tool by implementing the sustainability assessment of technologies and the technology selection methodology, and then tested the tool's capability for plant sustainability performance improvement.

3.1. Technologies and data

We selected two technologies, which we previously developed: Tech 1 – an environmentally benign cleaning rinsing and technology that can reduce chemical and water consumption in a cleaning-rinsing system, and Tech 2 – a water reuse technology to minimize wastewater generation in plating lines. Table 1 shows the selected sustainability indicators and the facility data collected for sustainability indicator evaluation. The data was collected from the National Center for Manufacturing Sciences' *Benchmarking Metal Finishing* (NCMS, 2000) and the P.I.'s earlier publications. The data were then normalized for the use of ISAE, as summarized in Table 2.

Table 1 - Sustainability indicators and data for case study.

Sustainability Indicator	Value Range		Facility	Tech. 1	Tech. 2
	Best	Worst			
Economic					
Value Added ($)	500,000	100,000	225,000	240,000	235,000
R&D Expenditure as Percentage of Sales (%)	15%	5%	7%	10%	9%
Investment on Education per Employee Training Expenses ($/$)	0.55	0.3	0.43	0.48	0.46
Charitable Gifts as a Percentage of New Income Before Tax (%)	7%	0%	3%	3%	3%
Environmental					
Total Raw Materials Used per Unit Value Added (Kg/$)	20	90	45	45	45
Net Water Consumed per Unit Value Added (Kg/$)	3	64	30	25	15
Hazardous Solid Waste per Unit Value Added (Kg/$)	0.01	0.04	0.04	0.04	0.04
Fraction of Raw Material Recycled within Company (%)	40%	0%	10%	10%	20%
Human Health Burden per Unit Value Added (t/$)	0.0012	0.005	0.0031	0.0034	0.0037
Social					
Benefits as a Percentage of Payroll Expense (%)	14%	5%	7%	7%	7%
Working Hours Lost as a Percentage of Total Hours Worked (%)	12%	25%	17%	20%	14%
Indirect Community Benefit per Unit Value Added ($/$)	0.3	0.06	0.19	0.22	0.25

Table 2 - Normalized indicator values of the facility and the two technologies.

Sustainability Indicator	Facility	Tech. 1	Tech. 2
Economic			
Value Added ($)	0.31	0.35	0.34
R&D Expenditure as Percentage of Sales (%)	0.20	0.50	0.40
Investment on Education per Employee Training Expenses ($/$)	0.52	0.72	0.64
Charitable Gifts as a Percentage of New Income Before Tax (%)	0.43	0.43	0.43
Environmental			
Total Raw Materials Used per Unit Value Added (Kg/$)	0.64	0.64	0.64
Net Water Consumed per Unit Value Added (Kg/$)	0.56	0.64	0.80
Hazardous Solid Waste per Unit Value Added (Kg/$)	0.00	0.00	0.00
Fraction of Raw Material Recycled within Company (%)	0.25	0.25	0.50
Human Health Burden per Unit Value Added (t/$)	0.50	0.42	0.34
Social			
Benefits as a Percentage of Payroll Expense (%)	0.22	0.22	0.22
Working Hours Lost as a Percentage of Total Hours Worked (%)	0.62	0.38	0.85
Indirect Community Benefit per Unit Value Added ($/$)	0.54	0.67	0.79

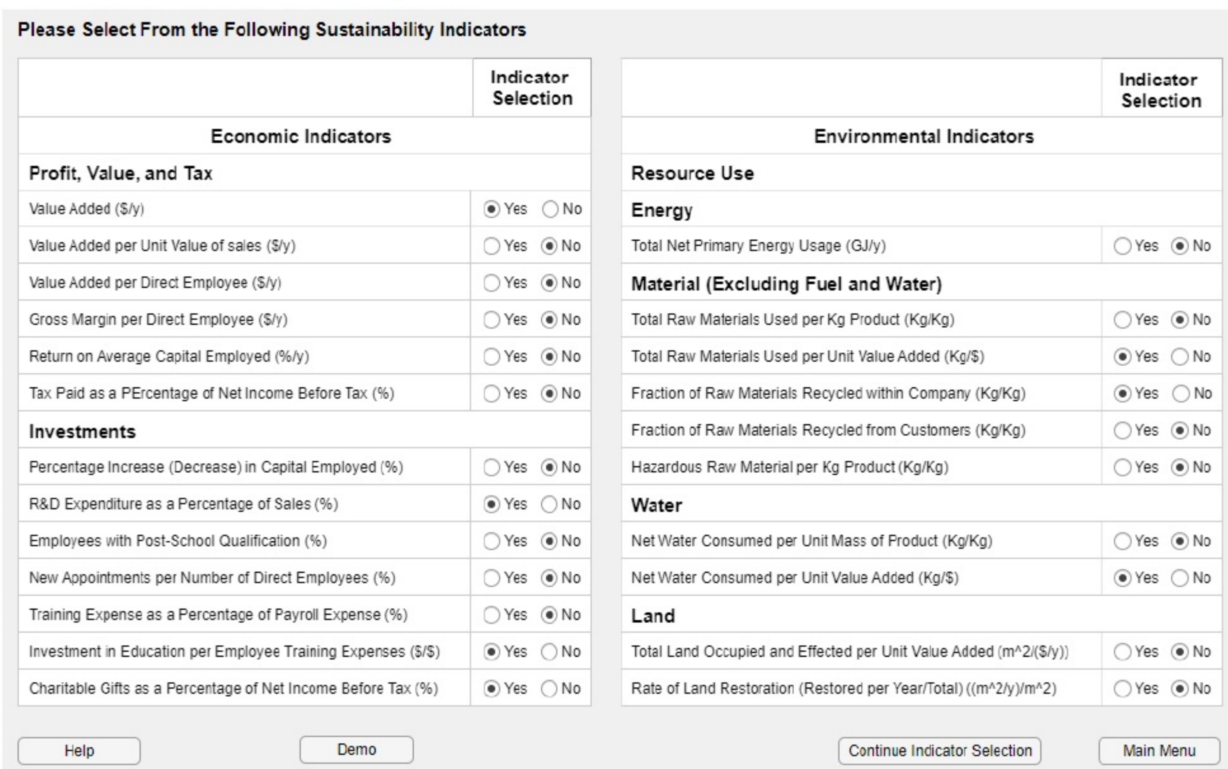
3.2. User interface and functions

The home screen of the ISAE tool is shown in Fig. 1. The tool has three clickable buttons at the bottom (as well as “Help” and “Exit”), named “Assessment” for conducting sustainability assessment; “Analysis” for performing sustainability analysis based on the assessment result; and “Decision Making” for deriving solutions for sustainability performance improvement.

Figure 1 - The home screen of the ISAE tool.

3.3. Sustainability indicator selection

As the first task for using the tool, a user needs to select a set of economic, environmental and social indicators. The selected indicators will be used for evaluating (i) the sustainability performance of an electroplating facility and (ii) the two listed technologies' capacity for performance improvement. As shown in Table 1, a total of twelve indicators are listed, including four economic indicators, five environmental indicators and three social indicators. Thus, in Figs. 2 and 3, these twelve indicators are selected, as per the selection of "Yes" that is associated with each individual indicator.



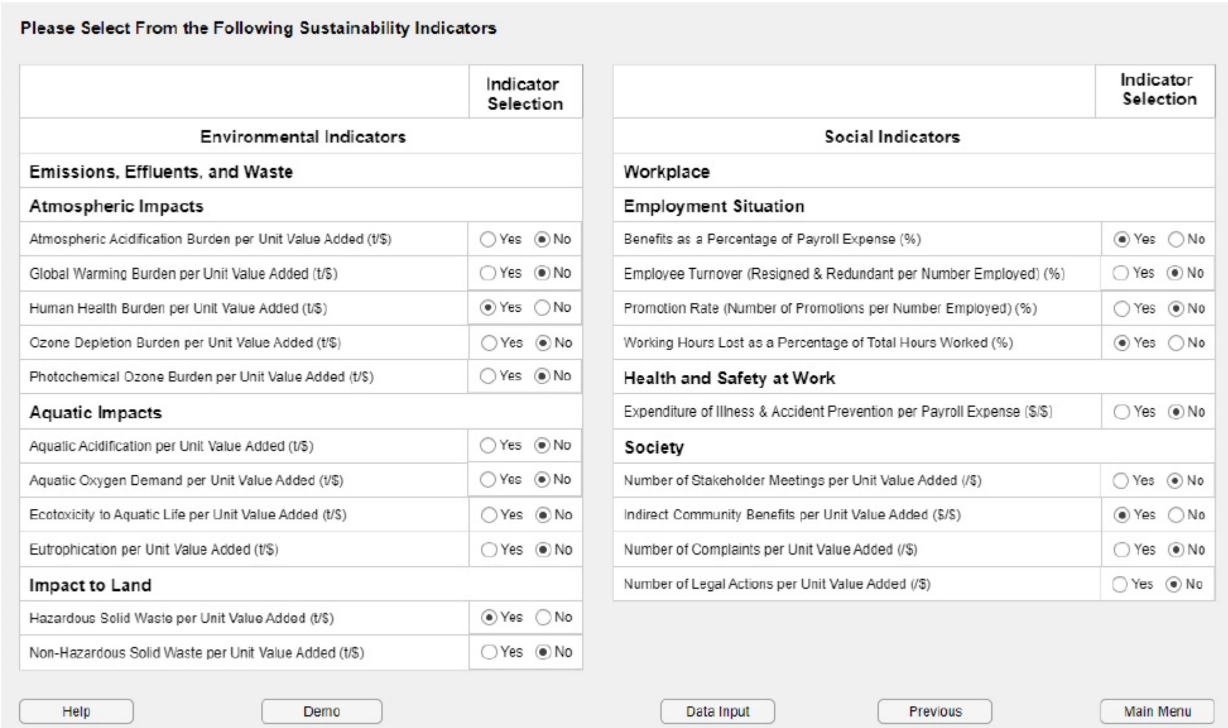
Please Select From the Following Sustainability Indicators

Economic Indicators	Indicator Selection
Profit, Value, and Tax	
Value Added ($/y)	(•) Yes ( ) No
Value Added per Unit Value of sales ($/y)	( ) Yes (•) No
Value Added per Direct Employee ($/y)	( ) Yes (•) No
Gross Margin per Direct Employee ($/y)	( ) Yes (•) No
Return on Average Capital Employed (%/y)	( ) Yes (•) No
Tax Paid as a PErcentage of Net Income Before Tax (%)	( ) Yes (•) No
Investments	
Percentage Increase (Decrease) in Capital Employed (%)	( ) Yes (•) No
R&D Expenditure as a Percentage of Sales (%)	(•) Yes ( ) No
Employees with Post-School Qualification (%)	( ) Yes (•) No
New Appointments per Number of Direct Employees (%)	( ) Yes (•) No
Training Expense as a Percentage of Payroll Expense (%)	( ) Yes (•) No
Investment in Education per Employee Training Expenses ($/$)	(•) Yes ( ) No
Charitable Gifts as a Percentage of Net Income Before Tax (%)	(•) Yes ( ) No

Environmental Indicators	Indicator Selection
Resource Use	
Energy	
Total Net Primary Energy Usage (GJ/y)	( ) Yes (•) No
Material (Excluding Fuel and Water)	
Total Raw Materials Used per Kg Product (Kg/Kg)	( ) Yes (•) No
Total Raw Materials Used per Unit Value Added (Kg/$)	(•) Yes ( ) No
Fraction of Raw Materials Recycled within Company (Kg/Kg)	(•) Yes ( ) No
Fraction of Raw Materials Recycled from Customers (Kg/Kg)	( ) Yes (•) No
Hazardous Raw Material per Kg Product (Kg/Kg)	( ) Yes (•) No
Water	
Net Water Consumed per Unit Mass of Product (Kg/Kg)	( ) Yes (•) No
Net Water Consumed per Unit Value Added (Kg/$)	(•) Yes ( ) No
Land	
Total Land Occupied and Effected per Unit Value Added (m^2/($/y))	( ) Yes (•) No
Rate of Land Restoration (Restored per Year/Total) ((m^2/y)/m^2)	( ) Yes (•) No

Help | Demo | Continue Indicator Selection | Main Menu

Figure 2 - Selection of economic and environmental (the 1st part) indicators.



Please Select From the Following Sustainability Indicators

Environmental Indicators	Indicator Selection
Emissions, Effluents, and Waste	
Atmospheric Impacts	
Atmospheric Acidification Burden per Unit Value Added (t/$)	○ Yes ◉ No
Global Warming Burden per Unit Value Added (t/$)	○ Yes ◉ No
Human Health Burden per Unit Value Added (t/$)	◉ Yes ○ No
Ozone Depletion Burden per Unit Value Added (t/$)	○ Yes ◉ No
Photochemical Ozone Burden per Unit Value Added (t/$)	○ Yes ◉ No
Aquatic Impacts	
Aquatic Acidification per Unit Value Added (t/$)	○ Yes ◉ No
Aquatic Oxygen Demand per Unit Value Added (t/$)	○ Yes ◉ No
Ecotoxicity to Aquatic Life per Unit Value Added (t/$)	○ Yes ◉ No
Eutrophication per Unit Value Added (t/$)	○ Yes ◉ No
Impact to Land	
Hazardous Solid Waste per Unit Value Added (t/$)	◉ Yes ○ No
Non-Hazardous Solid Waste per Unit Value Added (t/$)	○ Yes ◉ No

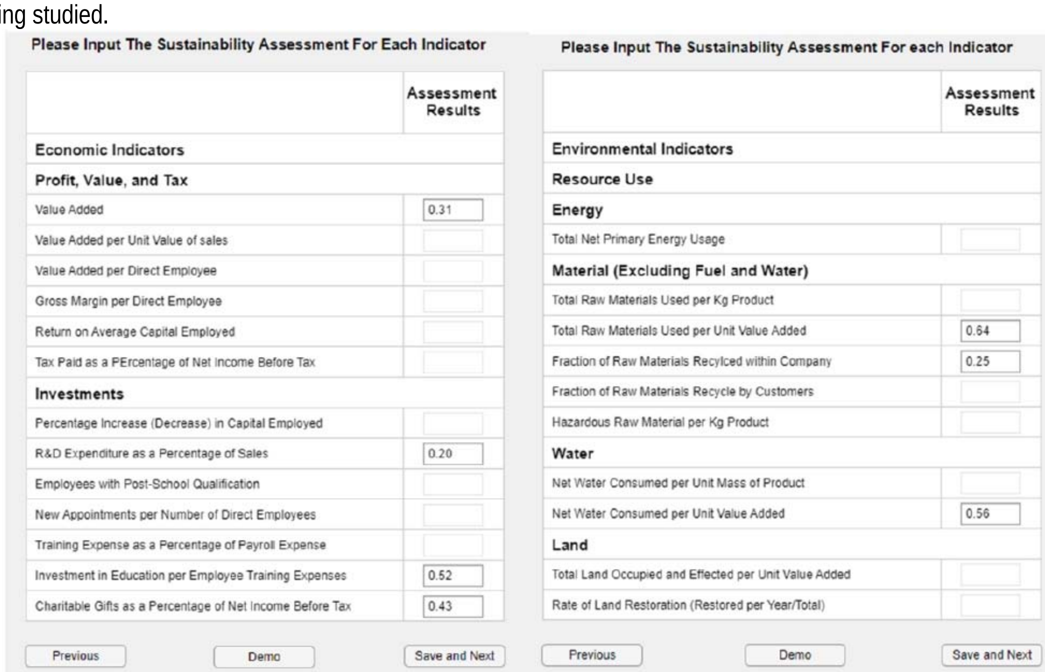
Social Indicators	Indicator Selection
Workplace	
Employment Situation	
Benefits as a Percentage of Payroll Expense (%)	◉ Yes ○ No
Employee Turnover (Resigned & Redundant per Number Employed) (%)	○ Yes ◉ No
Promotion Rate (Number of Promotions per Number Employed) (%)	○ Yes ◉ No
Working Hours Lost as a Percentage of Total Hours Worked (%)	◉ Yes ○ No
Health and Safety at Work	
Expenditure of Illness & Accident Prevention per Payroll Expense ($/$)	○ Yes ◉ No
Society	
Number of Stakeholder Meetings per Unit Value Added (/$)	○ Yes ◉ No
Indirect Community Benefits per Unit Value Added ($/$)	◉ Yes ○ No
Number of Complaints per Unit Value Added (/$)	○ Yes ◉ No
Number of Legal Actions per Unit Value Added (/$)	○ Yes ◉ No

Help | Demo | Data Input | Previous | Main Menu

Figure 3 - Selection of environmental (the 2nd part) and social indicators.

3.4. Data input of sustainability assessment.

Once the indicators are chosen, the next step is to input the normalized sustainability assessment results shown in Table 2 into the ISAE tool by clicking on the "Assessment" tab shown in Fig. 1. Figures 4 and 5 show the data input for the electroplating facility being studied.



Please Input The Sustainability Assessment For Each Indicator

Economic Indicators	Assessment Results
Profit, Value, and Tax	
Value Added	0.31
Value Added per Unit Value of sales	
Value Added per Direct Employee	
Gross Margin per Direct Employee	
Return on Average Capital Employed	
Tax Paid as a PErcentage of Net Income Before Tax	
Investments	
Percentage Increase (Decrease) in Capital Employed	
R&D Expenditure as a Percentage of Sales	0.20
Employees with Post-School Qualification	
New Appointments per Number of Direct Employees	
Training Expense as a Percentage of Payroll Expense	
Investment in Education per Employee Training Expenses	0.52
Charitable Gifts as a Percentage of Net Income Before Tax	0.43

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Please Input The Sustainability Assessment For each Indicator

Environmental Indicators	Assessment Results
Resource Use	
Energy	
Total Net Primary Energy Usage	
Material (Excluding Fuel and Water)	
Total Raw Materials Used per Kg Product	
Total Raw Materials Used per Unit Value Added	0.64
Fraction of Raw Materials Recylced within Company	0.25
Fraction of Raw Materials Recycle by Customers	
Hazardous Raw Material per Kg Product	
Water	
Net Water Consumed per Unit Mass of Product	
Net Water Consumed per Unit Value Added	0.56
Land	
Total Land Occupied and Effected per Unit Value Added	
Rate of Land Restoration (Restored per Year/Total)	

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Figure 4 - Data input for the selected economic and environmental (the 1st part) indicators.

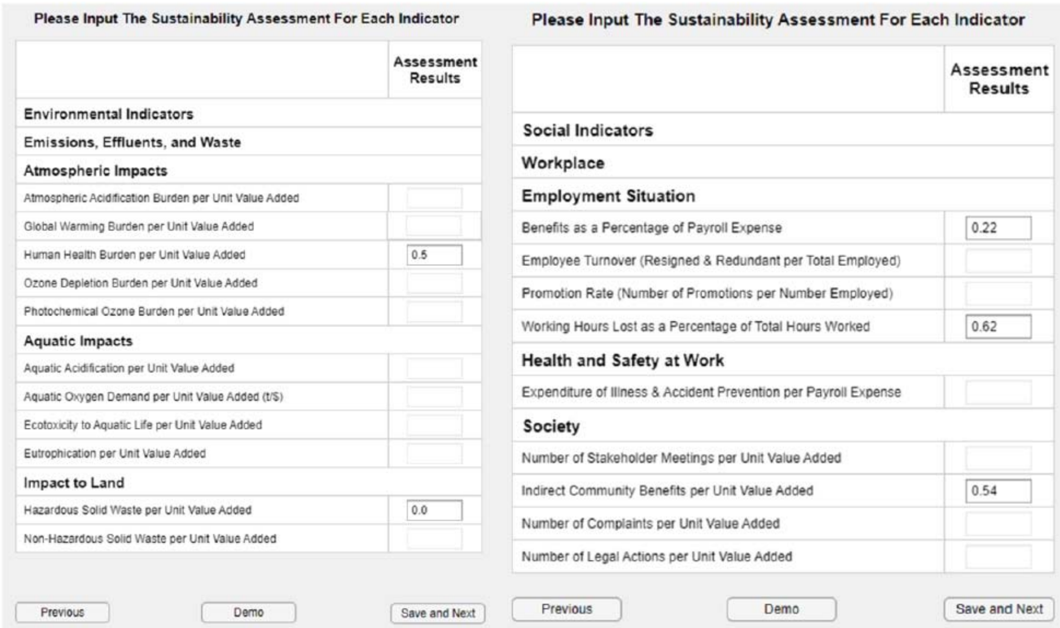

Figure 5 - Data for the selected environmental (the 2nd part) and social indicators.

3.5. Data input of the cost for technology adoption.

After inputting the assessment results shown in Table 2, the user needs to click on the "Decision Making" tab to let the ISAE tool analyze the technologies and select the best one, but this requires input of additional information. The user is prompted to input the number of technologies and the budget of each technology if adopted. Figure 6 shows a window for input of the cost data for the adoption of each of the two technologies, which are $47,000 for Tech. 1 and $32,000 for Tech. 2.

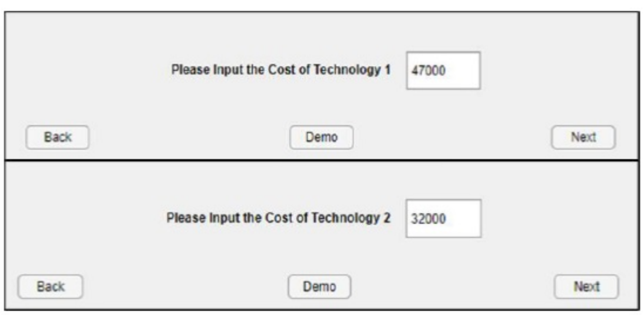

Figure 6 - Input of the cost data for Techs 1 and 2.

Figure 7 - Sustainability goal and budget input.

3.6 Data input of the facility's budget commitment and sustainability goal.

In order to identify a technical solution for a facility's sustainability performance improvement, the user must let the ISAE tool know the following: (i) the budget commitment by the facility, and (ii) the facility's expectation of the sustainability performance improvement, after known the current sustainability performance of the facility. In this case, the budget committed is $80,000, and the economic, environmental and social sustainability goals are set to 0.55, 0.50 and 0.60, respectively. Figure 7 demonstrates a tool's interface for the users to enter these data. Note that the figure also shows a set of other data: 0.37 as the "Current Economic Sustainability", 0.39 as the "Current Environmental Sustainability" and 0.48 as the "Current Social Sustainability". The data were calculated by the ISAE tool, based on the indicator-based sustainability assessment results shown in Table 2, as per the data in the column titled "Facility". The calculation method was reported in the 3rd quarterly report submitted in January 2021.

3.7. Data input of the technology's sustainability improvement capacity.

In Table 2, the right two columns contain the indicator-based sustainability performance improvement capacity of each of the two technologies. The calculation method was reported in the 8th quarterly report submitted in April 2022. The method needs to be implemented in the tool later. Figures 8 and 9 show the data input into the tool.

Please Input Values For The Following Economic Indicators

	Technology Assessment		
	Tech 1	Tech 2	Tech 3
Economic Indicators			
Profit, Value, and Tax			
Value Added	0.35	0.34	
Value Added per Unit Value of sales			
Value Added per Direct Employee			
Gross Margin per Direct Employee			
Return on Average Capital Employed			
Tax Paid as a PErcentage of Net Income Before Tax			
Investments			
Percentage Increase (Decrease) in Capital Employed			
R&D Expenditure as a Percentage of Sales	0.50	0.40	
Employees with Post-School Qualification			
New Appointments per Number of Direct Employees			
Training Expense as a Percentage of Payroll Expense			
Investment in Education per Employee Training Expenses	0.72	0.64	
Charitable Gifts as a Percentage of Net Income Before Tax	0.43	0.43	

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Please Input Values For The Following Environmental Indicators

	Technology Assessment		
	Tech 1	Tech 2	Tech 3
Environmental Indicators			
Resource Use			
Energy			
Total Net Primary Energy Usage			
Material (Excluding Fuel and Water)			
Total Raw Materials Used per Kg Product			
Total Raw Materials Used per Unit Value Added	0.64	0.64	
Fraction of Raw Materials Recylced within Company	0.25	0.50	
Fraction of Raw Materials Recycle by Customers			
Hazardous Raw Material per Kg Product			
Water			
Net Water Consumed per Unit Mass of Product			
Net Water Consumed per Unit Value Added	0.64	0.87	
Land			
Total Land Occupied and Effected per Unit Value Added			
Rate of Land Restoration (Restored per Year/Total)			

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Figure 8 - Data input for the selected economic and environmental (the 1st part) indicators.

Please Input Values For The Following Environmental Indicators

	Technology Assessment		
	Tech 1	Tech 2	Tech 3
Environmental Indicators			
Emissions, Effluents, and Waste			
Atmospheric Impacts			
Atmospheric Acidification Burden per Unit Value Added			
Global Warming Burden per Unit Value Added			
Human Health Burden per Unit Value Added	0.42	0.34	
Ozone Depletion Burden per Unit Value Added			
Photochemical Ozone Burden per Unit Value Added			
Aquatic Impacts			
Aquatic Acidification per Unit Value Added			
Aquatic Oxygen Demand per Unit Value Added			
Ecotoxicity to Aquatic Life per Unit Value Added			
Eutrophication per Unit Value Added			
Impact to Land			
Hazardous Solid Waste per Unit Value Added	0.0	0.0	
Non-Hazardous Solid Waste per Unit Value Added			

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Please Input Values For The Following Social Indicators

	Technology Assessment		
	Tech 1	Tech 2	Tech 3
Social Indicators			
Workplace			
Employment Situation			
Benefits as a Percentage of Payroll Expense	0.22	0.22	
Employee Turnover (Resigned & Redundant per Total Employed)			
Promotion Rate (Number of Promotions per Number Employed)			
Working Hours Lost as a Percentage of Total Hours Worked	0.38	0.85	
Health and Safety at Work			
Expenditure of Illness & Accident Prevention per Payroll Expense			
Society			
Number of Stakeholder Meetings per Unit Value Added			
Indirect Community Benefits per Unit Value Added	0.67	0.79	
Number of Complaints per Unit Value Added			
Number of Legal Actions per Unit Value Added			

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Figure 9 - Data input for the selected environmental (the 2nd part) and social indicators.

3.8. Technical solution identification.

After the input of all necessary information, the tool will do computations and output the results with the following possibilities: one or more solutions identified, or no solution. In this case, one solution is identified, *i.e.*, both technologies must be used, and the total cost is $77,000. The achieved economic, environmental and social sustainability performances are 0.58, 0.49 and 0.63, respectively, which are better than the preset goals listed in Fig. 6, *i.e.*, 0.55 for economic, 0.45 for environmental and 0.60 for social. The result is shown in Fig. 10, where a plotted sustainability cube provides the sustainability performance of the facility before and after technology adoption. It also reports that Tech. 1 or Tech. 2 alone is incapable of helping the facility to achieve preset sustainable goals.

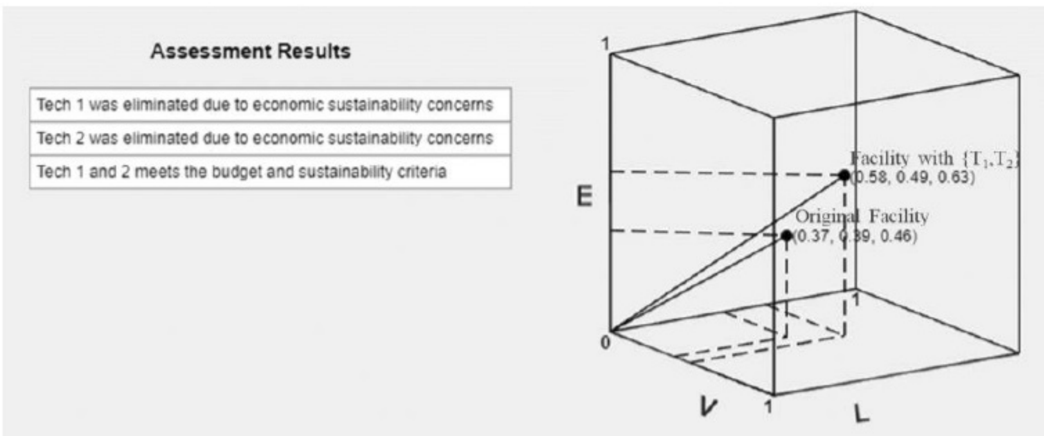

Figure 10 - Report on technical solution identification.

4. Discussion

As stated, the ISAE tool for solution derivation can lead to the generation of two types of reports:

1. Successful solution identification, which means one or two solutions are identified. Detailed information for each solution includes the technology name(s) and sustainability performance data (before and after technology adoption), and the cost for technology adoption. The case study described above is a successful example.

2. No solution identified. It will report the reasons for no solution, which may include, *e.g.*, the low commitment of funds for technology adoption, the technology's incapability of achieving the preset economic, environmental or social sustainability goal(s). In the case study, we encountered these types of problems. These included: (a) an initial lower budget commitment of $60,000, and (2) an environmental sustainability goal of 0.50. With the report from the ISAE tool, we readjusted the budget to $80,000, and the goal for environmental to 0.45.

4. Plan for the next quarter of the project

Next quarter, we plan to report our new progress on the tool development and on new case studies. In addition, we will report our research on the digital twin study with application of the Physics-Informed Neural Network (PINN) technology for an electroplating system.

5. References

1. J.P. Gong, K.G. Lou and Y. Huang, "Dynamic modeling and simulation for environmentally benign cleaning and rinsing," *Plating & Surface Finishing*, 84 (11), 63-70 (1997).
2. *Benchmarking Metal Finishing* (No. 0076RE00), National Center for Manufacturing Sciences (NCMS), Ann Arbor, MI (2000).
3. Y.H. Yang, H.R. Lou and Y. Huang, "Optimal design of a water reuse system in an electroplating plant," *Plating & Surface Finishing*, 86 (4), 80-84 (1999).

6. Past project reports

1. Quarter 1 (April-June 2020): Summary: *NASF Report* in *Products Finishing*; *NASF Surface Technology White Papers*, 84 (12), 14 (September 2020); Full paper: http://short.pfonline.com/NASF20Sep1
2. Quarter 2 (July-September 2020): Summary: *NASF Report* in *Products Finishing*; *NASF Surface Technology White Papers*, **85** (3), 13 (December 2020); Full paper: http://short.pfonline.com/NASF20Dec1
3. Quarter 3 (October-December 2020): Summary: *NASF Report* in *Products Finishing*; *NASF Surface Technology White Papers*, **85** (7), 9 (April 2021); Full paper: http://short.pfonline.com/NASF21Apr1.
4. Quarter 4 (January-March 2021): Summary: *NASF Report* in *Products Finishing*; *NASF Surface Technology White Papers*, **85** (11), 13 (August 2021); Full paper: http://short.pfonline.com/NASF21Aug1.
5. Quarter 5 (April-June 2021): Summary: *NASF Report* in *Products Finishing*; *NASF Surface Technology White Papers*, **86** (1), 19 (October 2021); Full paper: http://short.pfonline.com/NASF21Oct2
6. Quarter 6 (July-September 2021): Summary: *NASF Report* in *Products Finishing*; *NASF Surface Technology White Papers*, **86** (4), 19 (January 2022); Full paper: http://short.pfonline.com/NASF22Jan3
7. Quarter 7 (October-December 2021): Summary: *NASF Report* in *Products Finishing*; *NASF Surface Technology White Papers*, **86** (7), 17 (April 2022); Full paper: http://short.pfonline.com/NASF22Apr2
8. Quarter 8 (January-March 2022): Summary: NASF Report in Products Finishing; NASF Surface Technology White Papers, 86 (10), 17 (July 2022); Full paper: http://short.pfonline.com/NASF22Jul2
9. Quarter 9 (April-June 2022): Summary: *NASF Report* in *Products Finishing*; *NASF Surface Technology White Papers*, **87** (1), 17 (October 2022); Full paper: http://short.pfonline.com/NASF22Oct1
10. Quarter 10 (July-September 2022): Summary: NASF Report in Products Finishing; NASF Surface Technology White Papers, 87 (4), 17 (January 2023); Full paper: http://short.pfonline.com/NASF23Jan2
11. Quarter 11 (October-December 2022): Summary: *NASF Report* in *Products Finishing*; *NASF Surface Technology White Papers*, **87** (6), 19 (March 2023); Full paper: http://short.pfonline.com/NASF23Mar1
12. Quarter 12 (January-March 2023): Summary: *NASF Report* in *Products Finishing*; *NASF Surface Technology White Papers*, **87** (10), 20 (July 2023); Full paper: http://short.pfonline.com/NASF23Jul1

7. About the Principal Investigator

Dr. Yinlun Huang is a Professor at Wayne State University (Detroit, Michigan) in the Department of Chemical Engineering and Materials Science. He is Director of the Laboratory for Multiscale Complex Systems Science and Engineering, the Chemical Engineering and Materials Science Graduate Programs and the Sustainable Engineering Graduate Certificate Program, in the College of Engineering. He has ably mentored many students, both Graduate and Undergraduate, during his work at Wayne State.

He holds a Bachelor of Science degree (1982) from Zhejiang University (Hangzhou, Zhejiang Province, China), and M.S. (1988) and Ph.D. (1992) degrees from Kansas State University (Manhattan, Kansas). He then joined the University of Texas at Austin as a postdoctoral research fellow (1992). In 1993, he joined Wayne State University as Assistant Professor, eventually becoming Full Professor from 2002 to the present. He has authored or co-authored over 220 publications since 1988, a number of which have been the recipient of awards over the years.

His research interests include multiscale complex systems; sustainability science; integrated material, product and process design and manufacturing; computational multifunctional nano-material development and manufacturing; and multiscale information processing and computational methods.

He has served in many editorial capacities on various journals, as Co-Editor of the ASTM Journal of Smart and Sustainable Manufacturing Systems, Associate Editor of Frontiers in Chemical Engineering, Guest Editor or member of the Editorial Board, including the ACS Sustainable Chemistry and Engineering, Chinese Journal of Chemical Engineering, the Journal of Clean Technologies and Environmental Policy, the Journal of Nano Energy and Power Research. In particular, he was a member of the Editorial Board of the AESF-published Journal of Applied Surface Finishing during the years of its publication (2006-2008).

He has served the AESF and NASF in many capacities, including the AESF Board of Directors during the transition period from the AESF to the NASF. He served as Board of Directors liaison to the AESF Research Board and was a member of the AESF

Research and Publications Boards, as well as the Pollution Prevention Committee. With the NASF, he served as a member of the Board of Trustees of the AESF Foundation. He has also been active in the American Chemical Society (ACS) and the American Institute of Chemical Engineers (AIChE).

He was the 2013 Recipient of the NASF William Blum Scientific Achievement Award and delivered the William Blum Memorial Lecture at SUR/FIN 2014 in Cleveland, Ohio. He was elected AIChE Fellow in 2014 and NASF Fellow in 2017. He was a Fulbright Scholar in 2008 and has been a Visiting Professor at many institutions, including the Technical University of Berlin and Tsinghua University in China. His many other awards include the AIChE Research Excellence in Sustainable Engineering Award (2010), AIChE Sustainable Engineering Education Award (2016), the Michigan Green Chemistry Governor's Award (2009) and several awards for teaching and graduate mentoring from Wayne State University, and Wayne State University's Charles H. Gershenson Distinguished Faculty Fellow Award. Most recently, he received the AIChE Lawrence K. Cecil Award honoring his contribution in environmental sustainability research, education and leadership (2022).