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ORIGINAL ARTICLE

Energy conservation in a SME cluster: a system dynamics study

Virupaxi Bagodi · Deepankar Sinha · Shankara Naik

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Abstract SMEs are considered the backbone of a nation's economy as they contribute to exports, GDP, and employment. These firms face several challenges and aim to keep up their production targets and ensure the desired quality of products. In the process, they lose sight of energy consumption and emissions. Their electrical energy consumption is also considerable—in 2015, 13% or more (i.e., equivalent to 74 exajoules (EJ)) of the cumulative global energy demand was consumed by SMEs. Indian SMEs fail to take even simple energy-saving measures and lack effective implementation of such measures; SMEs account for almost 45% of GHG emissions annually. Previous studies have provided frameworks for implementing energy-efficient measures (EEM) and listed ways to ascertain their maturity in this regard. However, very little validation of these frameworks, reasons for low adaption of EEM, and actions required have been studied. Energy audit of an energy-intensive industry—washing units of jeans factories—revealed the areas requiring attention and the causes of high energy consumption. Interviews with operational managers and heads of units showed that they are non-adaptive to environmental requirements. A systems dynamics model was developed, and three scenarios were created to demonstrate the plausible energy savings and introduce learning among managers. The study proposes a changed KPI, the means to evaluate returns, and mental models for decision-making.

V. Bagodi (✉)
Government Engineering College, Talakal 583238, India
e-mail: virupaxibagodi@yahoo.com

D. Sinha
Indian Institute of Foreign Trade, Kolkata 700107, India

S. Naik
Government Engineering College, Haveri 581110, India

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Introduction

Small and medium enterprises (SMEs) constitute a large proportion of economic activity (Boocock & Shariff, 2005). They are the lifeblood of modern economies (Ghobadian & Gallear, 1996) worldwide (Singh et al., 2008). SMEs' contribution through industrial production (Pooja 2009), exports (Venkatesh & Muthiah, 2012), and employment (Wang, 2016) is immense. European Union also relies on SME contributions—there are around 24 million SMEs as in 2016. As in 2016, they contributed about 56.8% (4030 billion euros) of gross value added and provided approximately 66% of jobs (over 93 million) (Wang et al., 2020). Similarly, Indian SMEs contribute about 30% to industrial production and employ more than 110 million people (George & Srinivas, 2020); it is a major job creator and the backbone of the Indian economy, contributing over 28% to India's GDP and about 48% to the country's exports (Dewan, 2020). Governments across countries aim to support SMEs. EU, among other initiatives, has stressed the need for innovation in SMEs and pegged 3% of GDP on research and development activities (Hervás-Oliver et al., 2021). The Indian government has initiated several initiatives to implement lean and green practices and improve SME soft capabilities such as marketing and skill development, export promotion, and similar (Thanki & Thakkar, 2018). However, despite many initiatives from the government, SMEs are not free from challenges.

SMEs face challenges: high credit cost (Wang et al., 2020), low levels of innovation (Hervás-Oliver et al., 2021), severe competition (Masroor and Muhammad, 2019), traditional manufacturing methods and practices (Sahoo and Yadav 2018), absence of cost reduction strategies (Thollander & Ottosson, 2008), and lack of cleaner production methods (Khuriyati & Denok Kumalasari, 2015).

The world adopts the circular economy (CE) as the new order for survival. It calls for a system-level approach to minimizing waste, contamination, pollutants, and non-renewable energy consumption (Bucknall, 2020; Gardetti, 2019; Krysovatyy et al., 2018; Moreno-Mondéjar & Cuerva, 2020). However, SMEs seem to struggle to adopt this order of doing business. The firms are yet to adopt CE holistically and are in a transition phase. EU has announced its action plan on CE implementation (Ünal et al., 2019). However, the execution of CE as a well-planned strategy is less seen (Brendzel-Skowera, 2021).

In 2015, SMEs consumed 13% or more (i.e., equivalent to 74 exajoules (EJ)) of the cumulative global energy demand (Prashar, 2017). Thiruchelvam et al. (2003) assert that even simple energy-saving measures do not prevail in Indian SMEs; they lack effective implementation of energy efficiency measures (Hampton, 2019; Prashar, 2017) and account for almost 45% of GHG emissions annually (Prashar, 2019). They are threatened with closure for emitting greenhouse gases causing environmental hazards. The commitment comes from the top, as the Hon'ble Prime Minister of India announced India's plan to meet 50% energy requirement through renewable energy sources by 2030 and assures to reach net-zero emission by 2070 (Sengupta 2021). This commitment emphasizes India's vision to counter greenhouse gas emission and strategy to mitigate the energy crisis. An in-depth study of an energy-intensive SME cluster can lead to an understanding of prevailing issues and challenges. The outcomes are required to draw up an action plan to achieve India's mission for optimized energy consumption and cleaner production.

The extant research works provide an energy sustainability (ES) framework for Indian SMEs, emphasizing organization, visualizations and optimizations, and ES reporting systems (Prashar, 2019). However, this study fails to recognize the maturity of SMEs to acknowledge the need for energy-efficient machines, long-term versus short-term benefits, and the need to adapt to the changing environmental requirements and options available. Prashar (2017) suggested the EE maturity model that stresses accounting of benefits of energy savings and non-financial benefits such as enhanced reputation, higher returns, and similar but have not been adequately tested in Indian SMEs. Besides, the studies have failed to identify the challenges in meeting sustainability goals.

SMEs are open and purposeful systems (Ackoff, 1971); hence, they interact with the environment that provides opportunities and resources and poses threats (Perrow, 1970). Organizations need to interact and exchange materials, humans, information, and technology with the environment for sustenance and growth (Scott, 2003). A firm needs to learn and adapt to changes to enhance performance. Learning organization literature says that "single-loop learning" leads to achieving goals and objectives with no change in practices and beliefs (García-Morales et al., 2009; Sterman, 2000). In a dynamic environment, traditional techniques and policies are inadequate (Love et al., 2000) for a company to survive in the long run, while in double-loop learning, the underlying policies and goals are questioned to change beliefs and values in a system (Argyris & Schön, 1996; Senge et al., 1994). An organization that learns augments performance creating a sustainable competitive advantage (Fareed et al., 2016; Love et al., 2000). A system dynamics approach can identify the causality and determine learning abilities or disabilities (Cosenz & Noto, 2016).

In this paper, the authors have a fourfold aim—identifying the causes of high energy consumption, the ways to mitigate the same, ways to lower GHG emissions, and the deterrents to energy efficiency strategy implementations (the learning disabilities). Thus, it attempts to answer the major research question: How can Indian SMEs conserve energy and be sustainable? The study is done in a select SME cluster—the jeans washing cluster located in Karnataka, India. The study is based on data collection through an energy audit, identifying cause and effect, state of learning using systems dynamics, and capturing the managerial nuances through interviews.

This article has six sections. The following section discusses extant literature on the subject, followed by methodology. The "Jeans washing cluster: energy data analysis" section gives the findings, and the "Discussions" section discusses the same. The last section concludes the study.

Literature review

A literature review is presented in four sections: SMEs, energy management, system dynamics, and organizational learning.

SME: definition and growth

Gibson and van der Vaart (2008) and Berisha and Pula (2015) assert that it is challenging to define SME. Storey (1994) said that many differences exist due to their size and capital invested; hence, there is no single and uniformly accepted definition. Most nations have different definitions. In general, commonly employed criteria include employment, annual turnover, and capital investment. As per the Indian MSMED Act 2006, manufacturing SMEs are defined based on the investment in plant and machinery. Small enterprises are firms where the investment in plant and machinery or equipment and turnover are within INR 100 million and INR 500 million, respectively. A medium enterprise has an investment in plant and machinery not exceeding INR 500 million, and turnover does not exceed INR 2500 million.

Subrahmanya et al. (2010), Singh et al. (2012), and Jaswal (2016) assert that, in India, SMEs significantly contribute to the economy. Their contribution in terms of GDP (Vashisht et al., 2016), exports (Mohanty, 2010; Neha, 2019), and employment (Javalgi & Todd, 2011; Venkatesh & Muthiah, 2012) are considerable. The numbers of working MSMEs in 2008–2009 and 2018–2019 were 39.37 and 63.12 million, while the employment the sector provided was 88.08 and 116.50 million people. Compounded annual growth rate (CAGR) of working units and jobs was around 4.83% and 2.84%, respectively. Over 120 million people, i.e., nearly 10% of India's population, were employed in this sector in 2019–2020. Sector's contribution to exports has grown from about 30 to nearly 50% during the same period.

SMEs are subjected to intense competition (Nayar, 2011; Raravi et al., 2013) and struggle hard to survive (Prasanna et al., 2019). Despite numerous protection and policy measures for the past years, SMEs have remained mostly small, technologically backward, and lack competitiveness (Bagodi & Raravi, 2021; Mulhern & Stewart, 2003). According to the census of 2006–2007 and subsequent MSME reports, sickness in industries has been growing. It is expected to rise (Mital, 2007; Muthu, 2015). In their report on MSMEs, the government of India mentioned that sickness and closure of firms is one of the perplexing problems in the country. Economic Times newspaper reported that, in this pandemic, one in every three firms is likely to shut down.

Energy efficiency

Energy is crucial to accomplishing socio-economic growth (Vimala & Kumar, 2016) and vital for industry (Saidur et al., 2011). Efficient energy use can be a sound business strategy in manufacturing (Naik & Bagodi, 2021) as it significantly reduces production costs (Catarino et al., 2015; O'Rielly & Jeswiet, 2015). Manufacturing units across the globe contemplate energy efficiency to counter competition (Therkelsen et al., 2014) by achieving savings in energy costs (Shrouf & Miragliotta, 2015). Climate change demands a reduction in energy consumption in manufacturing processes (Menghi et al., 2020). Energy auditing is a pragmatic way to assess the performance of energy systems (Sequeira & Joanaz de Melo, 2020).

Energy audits are the direct tools to reduce energy consumption (Redmond & Walker, 2016; Su et al., 2013), focusing on technical and economic issues (Palm & Backman, 2020). Auditing helps adopt energy efficiency measures (Fleiter et al., 2012) and overcome the barriers to energy efficiency (Paramonova & Thollander, 2016). The manufacturing sector should support sustainable development by reducing energy consumption and improving efficiency to conform with climate change requirements (Menghi et al., 2020). For every kilowatt-hour of electricity generation using coal, 0.00707 kg of SO_2, 0.93 kg of CO_2, 0.0043 kg of NO_x, and 0.0046 kg of CO are emitted (Saxena, 2016).

Industrial motors consume most of the energy used in industries (Saidur, 2010) and, therefore, present considerable potential for energy efficiency (Trianni et al., 2019). This aspect should be explored for efficiency improvements (Tandel & Shukla, 2019) as they account for about 58% of losses (Jayamaha, 2008). Energy-efficient motors use low-loss materials (Saidur & Mahlia, 2009), and their efficiency is 8% higher than standard motors (Zabardast & Mokhtari, 2008). Energy efficiency leads to cost reduction and minimizes environmental degradation (Costa-Campi et al., 2015).

System dynamics

System dynamics has been developed by JW Forrester in Sloan School of Management as a modelling and simulation technique to help managers make decisions in a complex situation (Forrester, 1961; Roberts, 1978). System dynamics method is based on servomechanism (feedback loops), decision-making, and simulation (Coyle, 1977; Forrester, 1961; Wolstenholme, 1990). It has been developed for efficient decision-making (Graham et al., 1992; Morecroft & Glucksman, 1998; Senge, 1990), which is governed by the policies or decision rules, guides the managers on how to take actions. Simulation speeds and strengthens the learning feedback (Sterman, 2000) and thus provides decision-makers an environment to watch, understand, and analyze the effects of their actions (Sinha et al., 2020). It is a way of studying the behavior of the systems to understand how policies, decisions, structure, and delays are interrelated to influence growth and stability. It can capture hard and soft variables and provide managers with valuable means to explore the system's structure and carry out experiments to identify growth or stability policies (Coyle, 2000).

Causal loops form the structure of a system. They may be balancing exhibiting goal-seeking behavior or reinforcing, indicating growth (decay). A system dynamics model can also be represented in a flow diagram consisting of level, rate, and auxiliary variables. The levels are accumulations or stocks and can occur in physical and information flows. The rates are the system's inflows and outflows, and their difference is the level. Different factors, i.e., auxiliary variables, impact the flow rates.

Organizational learning

Most scholars view organizational learning as a process that unfolds over time and link it with knowledge acquisition and improved performance (Garvin, 1993; Popescu et al., 2011). Two types of organizational learning most often cited are adaptive and generative learning (Argyris & Schön, 1978)—also referred to as single-loop learning and double-loop learning in literature. The former involves the detection and correction of an error. The existing policies of the decision-makers are not questioned (Parker and Stacey, 1995). There is no change in the fundamental beliefs, boundaries, time horizon, goals, and values (Sterman, 1994). But in a dynamic and complex world, double-loop learning is more relevant (Love et al., 2000). One needs to question the governing variables themselves and subject them to inquiry. Argyris and Schön (1978) describe this as double-loop learning. It may lead to modifications in the governing variables and, thus, a shift in framing strategies and consequences (Bagodi & Mahanty, 2021). In double-loop learning, changes in the mental models take place due to openness. This aspect is precisely portrayed in Fig. 1.

SME managers are confronted with an increasingly unstable, complex, and changing economic context (Dominguez et al., 2010). In most cases, they limit their learning to "an adaptive" learning (Gibb, 1997; Senge, 1990). Owners-managers of Indian SMEs often do not have enough managerial insights and organizational capabilities (Majumdar & Manohar, 2016); hence, Indian SMEs' survival depends on their capacity to acquire new knowledge (Prasanna et al., 2019; Puthusserry et al., 2020; Rammer et al., 2009). It requires individuals and organizations to develop new ways of looking at the world (Senge, 1990) and acquire "generative learning" capabilities by being open to the real world.

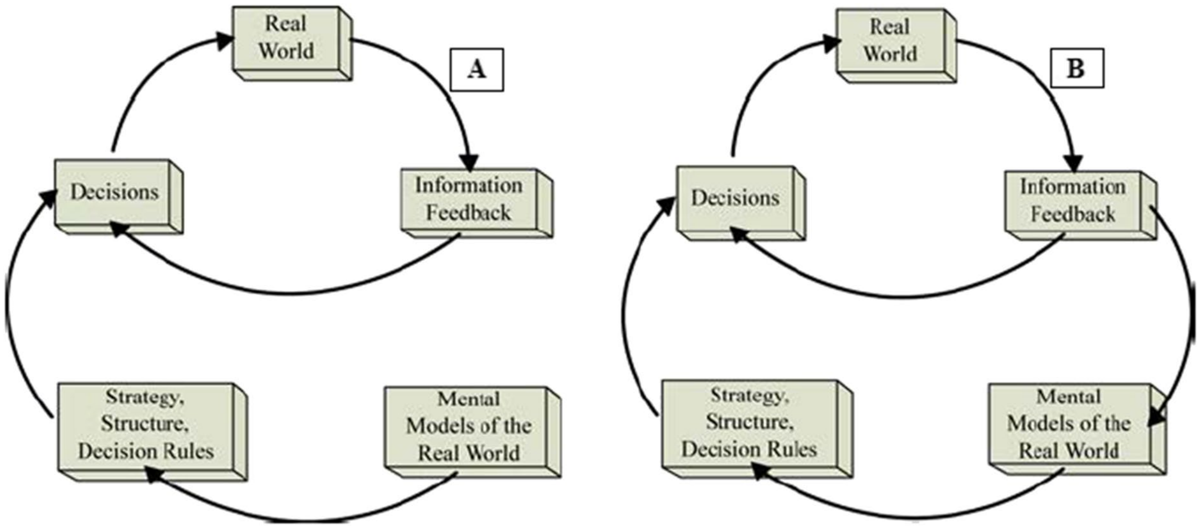

Fig. 1 **A**, **B** Single- and double-loop learning (adapted from Sterman, 2000)

Research methodology

The study was based on a three-stage approach—(i) an energy audit of select firms of jeans cluster in the state of Karnataka, India; (ii) interviews of operational managers and organization heads—capturing their decision-making process; (iii) system dynamics modelling of mental (decision-making) models and its simulation identifying efficiency and energy consumption over time and the decision-making process to regulate energy consumption.

The energy audit

The audit was done in stages—identifying the major steps in production and their energy consumption. The stage which consumed higher electrical energy was considered for in-depth auditing—determining the equipment—their load, energy usage, and efficiency levels. The audit took 6 months (in the year 2019).

The sample profile

SMEs in India exist in clusters, i.e., firms located in an area having common facilities availed by the units. The authors discussed with the Joint Director of the District Industry Centre and SME association officials and sought permission to carry out auditing.

Jeans' manufacturing consists of stitching, washing, and packaging. A preliminary study was conducted in a few units of all types. It was found that the washing industry is energy-intensive and energy cost is nearly 10% of the production cost.

The washing cluster consisted of 80 units, of which detailed auditing was planned in 20 units. Figure 2 presents the revenue profile of the 20 units selected for the study. Auditing was carried out with the help of sophisticated data measuring and acquisition equipments/instruments. Some of the instruments used in the study include a digital multimeter, digital tachometer, tong tester, power factor meter, and digital and manual distance measuring unit.

The respondents' profile, shown in Table 1, indicates that life span is greater than 25 years with a low workforce—not exceeding ten persons. Fifteen out of 20 firms agree that energy cost comprises a significant expense share.

Jeans washing cluster: energy data analysis

Washing of jeans or denim is a process that gives a final touch to stitched pants. Washing gives an aesthetic finish to the fabric, and it improves the comfort

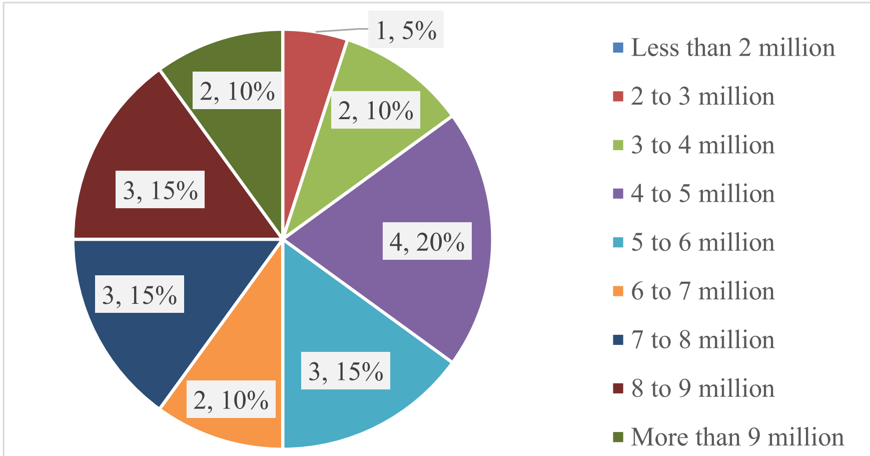

Fig. 2 Annual revenue of the sample

Table 1 Profile and responses of the sample

Sl. no	Description	Response			
1	Type of enterprises	Small enterprises (all 20)			
2	Number of employees	8–10 persons (all 20)			
3	Age of the enterprise	More than 25 years (all 20)			
4	Amount spent on electricity	All enterprises spend more than 10%			
5	Significance of energy cost	Energy is our most significant expense	Energy is one of our major expenses		While important, energy is not a major expense
		1	15		4
6	Most of the energy is used in its operations	Yes, exactly		Yes, approximately	
		3		17	

and softness of the jean. This involves various washing processes such as hard wash, potassium permanganate wash, acid, and hydrogen peroxide wash, dyeing, acid and enzyme wash, soaping and detergent wash, and softener wash.

This industry uses washing machines, water lifting systems, compressors, effluent treatment plants, boiler, and tumbler systems. The loadings of various devices used in the washing industry across 20 units are mentioned in Table 2. The energy consumption pattern of the cluster is shown in Fig. 3. It was found that all machines/equipment were powered by electrical "motors" only. It was noted that around 97% of overall electricity is consumed by these motors only. The cluster uses 1360 motors of varying capacity as part of the different machines/equipment consuming 2,390,851 kWh annually. The average efficiency of a motor was computed as 63%.

The authors found it interesting to extend the study to understand their practices and policies in managing the machines, especially motors, and capture the dynamics. Their maintenance schedule, which includes lubrication, alignment of bearings and shafts, the type of motors in use, protection, and foundation provided to the motors located in an open environment, repair, and replacement of motors were studied extensively. The discussion led to the development of a causal loop diagram and system dynamics model, which are discussed in the following sections.

Table 2 Electricity load of various equipments/machines used in jeans washing industry

Sl. No.	Washing Unit	Washing Machine					Compressor			Water Lifting	Effluent System					Tumbler System						Boilers				Total load in hp	Sanctioned Load in hp
											Blower		Dirty Water		Pure Water	Blower			Drum			Blower		Water			
Motor Power (hp)		3	5	7.5	10	12.5	5	7.5	10	3	2	3	2	1	1	1.5	2	3	1.5	2	3	3	5	1	2		
1	A	2	1	3	--	1	--	--	1	1	--	1	1	--	1	--	3	--	--	--	3	--	1	--	1	87	66
2	B	2	--	1	--	1	1	--	--	1	1	--	--	1	1	--	--	2	--	--	2	--	--	--	--	50	66
3	C	1	--	2	1	--	--	--	1	1	1	--	--	1	1	--	2	--	--	2	--	1	--	--	1	58	66
4	D	3	2	2	1	--	--	--	1	1	--	1	--	1	1	--	2	--	2	--	--	--	--	--	1	71	66
5	E	2	--	1	1	--	1	--	--	1	1	--	--	1	1	3	--	--	--	--	3	1	--	--	1	54	66
6	F	3	--	2	--	2	1	1	--	1	1	--	--	1	1	--	2	--	--	2	--	1	--	--	1	81.5	66
7	G	2	1	1	--	1	--	1	--	1	--	1	--	1	1	--	1	1	--	1	1	1	--	--	1	61.5	66
8	H	--	1	4	--	--	--	1	--	1	--	1	--	1	1	--	1	1	--	1	1	--	--	--	--	60.5	66
9	I	--	2	3	--	1	--	--	1	1	1	--	--	1	1	--	--	2	--	--	2	1	--	--	1	79	66
10	J	--	3	--	1	2	--	1	--	1	1	--	--	1	1	--	--	2	--	--	2	1	--	--	1	81.5	66
11	K	--	4	5	--	--	--	1	--	1	--	1	--	1	1	--	2	--	--	2	--	1	--	--	1	86	66
12	L	--	2	2	1	--	1	1	--	1	1	--	--	1	1	--	2	--	--	2	--	1	--	1	--	66.5	66
13	M	--	1	2	1	--	1	--	--	1	--	1	--	1	1	--	2	--	--	2	--	1	--	--	1	56	66
14	N	1	1	3	1	--	2	--	--	1	1	--	--	1	1	--	1	2	--	1	2	1	--	--	1	78.5	66
15	O	1	1	1	1	--	--	--	1	1	--	1	--	1	1	--	--	2	2	--	--	1	--	--	1	57.5	66
16	P	1	2	1	--	1	--	--	1	1	1	--	--	1	1	--	2	--	--	2	--	1	--	--	1	63	66
17	Q	2	1	2	--	2	--	1	--	1	1	--	--	1	1	--	2	--	--	2	--	1	--	--	1	78.5	66
18	R	3	1	1	--	--	--	1	--	1	1	--	1	1	--	--	2	--	--	2	--	1	--	1	--	49	66
19	S	2	--	2	--	2	--	1	--	1	1	--	--	1	1	2	--	--	--	--	2	1	--	--	1	74.5	66
20	T	3	1	3	--	2	--	--	1	1	1	--	--	1	1	1	2	--	--	2	1	1	--	--	1	96	66

The heat consumption in washing and drying are also high—close to 100 °C and between 140 and 200 °C, respectively (Kalogirou, 2003; Mekhilef et al., 2011). These previous studies show the use of solar industrial powers to meet the heating requirements in different industries, including textiles

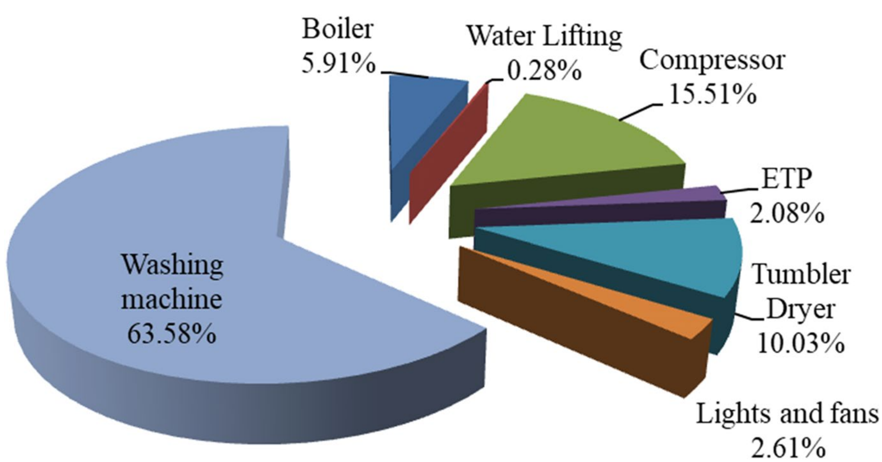

Fig. 3 Energy consumption pattern in jeans washing cluster

Causal loop diagram and system dynamics modelling

Jeans' manufacturing is prevailing since the 1980s. The business is almost stable and has vast export potential. A newspaper reports that the manufacturing cluster (including washing) has employed more than 70,000 people. Most of the washing units are either small or micro-units. For almost a decade, the number of exclusive washing units has remained at 80. The causal loop diagram focusing on "motors" built based on the mental models of the owners/managers of units is presented in Fig. 4. The emissions were not part of the discussion but have been included for academic interest. The stock-flow diagram is shown in Appendix (Figs. 12 and 13).

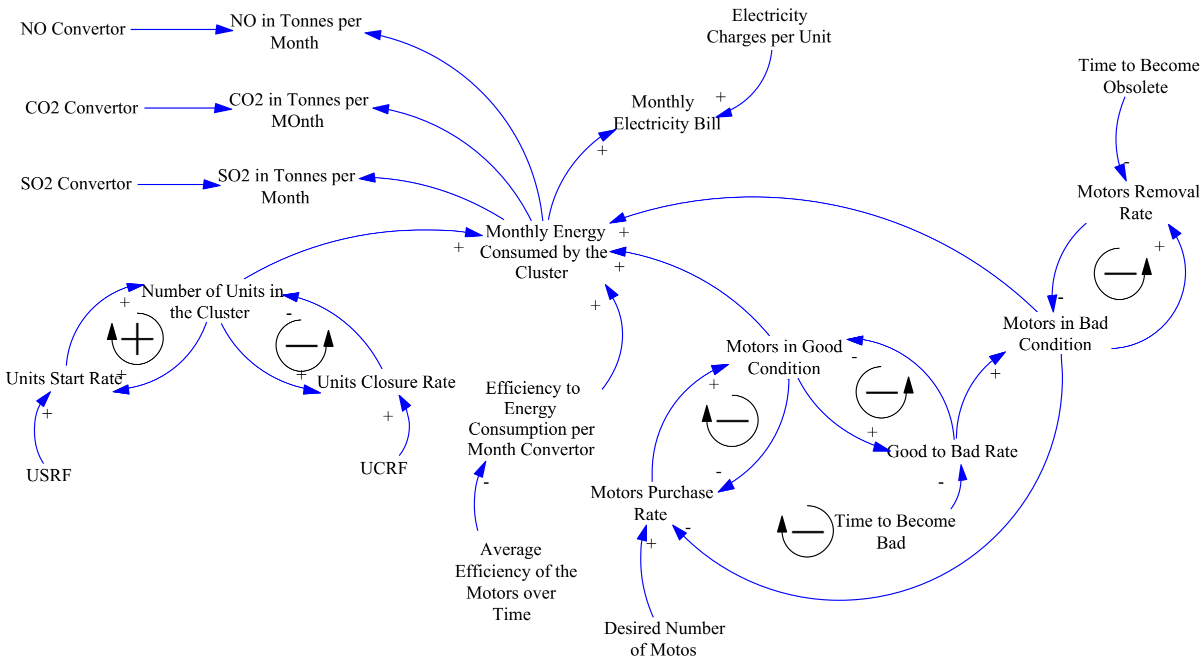

Fig. 4 The causal loop diagram

Single-loop learning in action

It is evident from Fig. 4 (similar to Fig. 1A) that there is no connection with the environment regarding energy consumption and related policies. The decision to replace or buy a new motor is based on the state of the existing motor, i.e., its failure rates. The same should have also considered the overall electricity consumptions and charges. That is, ways to minimize energy bills or search for energy-efficient motors should also be considered for a new purchase or replacement decision. Thus, the managerial decisions have no connection with the environment—looking for energy-efficient motors. Hence, altering the mental models can result in an energy conservation approach.

System dynamics modelling

Since the study focuses on motors and their electricity consumption, the model is built accordingly. The motors are locally made and classified as either good or bad. Owing to the way motors are used and handled, in almost 2 years, they attract problems. During this period, the efficiency of the motors was decreasing due to overloading and other reasons. The problem is generally noticed through overheating, spark, and noise symptoms. The problems may range from a minor blocking of the ventilation leading to overheating, winding damages, damaged stator/rotor, wobbling shafts, misalignment, and worn-out bearings. The repair brings back the motors into operation but with reduced efficiency. Over 10–15 years, these machines become unusable and call for replacement. The efficiency decides how many units of energy are consumed by a motor. Two table functions are necessary to capture non-linear dynamics—one, efficiency as a function of time, and the other, energy consumption as a function of efficiency. These have been developed based on the data gathered during the study period and information provided by the managers/owners, the motor repairers, and the supervisors. The previous 5 years' energy consumption pattern was computed based on bills obtained from the accounts department. These table functions are presented in Figs. 5 and 6. The numbers of units in the cluster vary because of the units' closure and start rate. The number has been stable during the last decade and remained at 80 units. The energy consumed by the cluster is equal to the product of the number

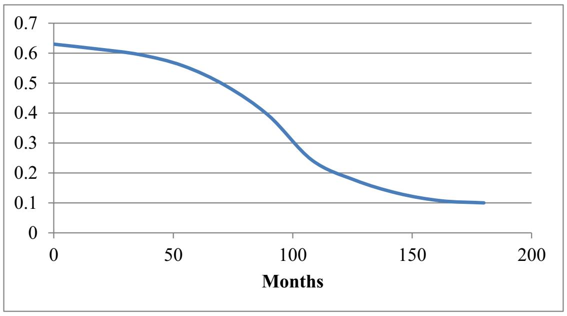

Fig. 5 Relation between time (months) and efficiency of motors

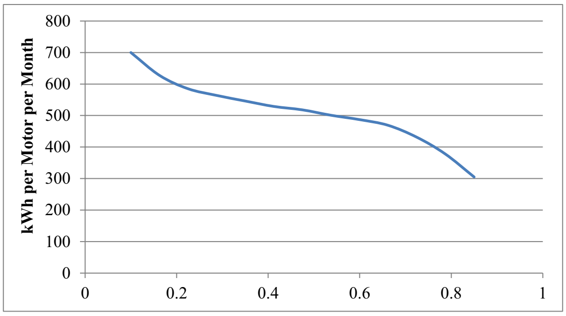

Fig. 6 Relation between efficiency of motors and energy consumption per month

of units, the total number of motors, and the energy consumed by each motor.

Model validation

The system dynamics literature stresses that the validity of the model primarily depends on the purpose for which it has been developed (Bagodi & Mahanty, 2015). It is mainly done to have confidence in the model (Mohapatra et al., 1994). Since structure gives rise to behavior (Forrester, 1961), behavior replication is one of the important validation tests. Validation depends on the extent to which it satisfies the purpose (Forrester & Senge, 1980).

The behavioral replication test was conducted considering electricity consumption data. The monthly electricity consumption of 20 units over 12 months (October 2018–September 2019) was gathered. The monthly average of these 20 units multiplied by 80 is considered the actual energy consumed by the cluster for that month. (For example, energy consumption values for October 2018 of 20 washing units are added and then divided by 20 to get the average energy consumption of one unit. This average is then multiplied by 80 to get cluster energy consumption for October 2018.) The simulated values are obtained by running the model in Stella 9.1.4 software with dt at 0.05 months employing the Runge–Kutta 4 method of integration for 12 months. The actual and simulated values from October 2018 to September 2109 are presented in Fig. 7. The Spearman Rho correlation coefficient is found to be 0.98, and the R^2 value is found to be 0.96. Both values are statistically significant at the 0.01 level. This result indicates a high amount of correlation between actual and simulated values. The mean absolute percentage error was found to be 4.61%. Bagodi and Mahanty (2013) said that MAPE of less than 5% is a good indicator of system dynamics-based models' prediction.

Each variable's dimension (units) and parameters were considered while formulating the model equations. It was found that dimensional consistency is maintained throughout the model. Further, it is ensured that all the table functions used in the model have dimensionless inputs and outputs.

There should be a corresponding real-world counterpart for every variable in the model. This aspect was also checked for and found to be consistent. A boundary condition test was also conducted and

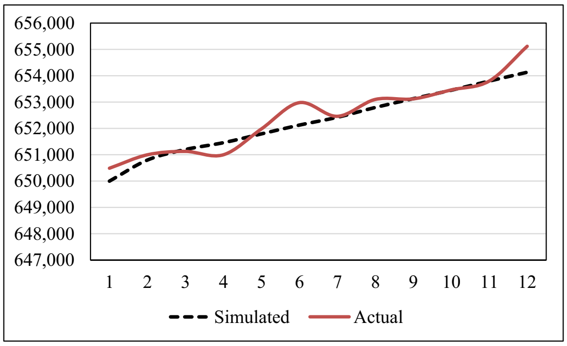

Fig. 7 Actual and simulated values of monthly energy consumption by the entire cluster

found to be adequate. These tests ensure confidence in the model.

Base model run

The system dynamics model was developed using Stella 9.1.4. The model was simulated for 180 months with dt at 0.1 using Runge–Kutta 4 integration method. The simulated results of key variables are presented in Fig. 8.

It can be seen from the figure that all the variables are increasing and then attain stability. The electricity consumption by the cluster over 15 years is found to be 139,017,572 kWh, while the CO_2, NO, and SO_2 emissions over the same period are found to be 109,893,390; 543,559; and 827,155 t, respectively. These emissions are indirect as the cluster consumes electricity supplied by the Government agency.

It is interesting to observe that despite the number of units in the cluster being constant at 80 units and the number of motors employed by the cluster unchanged at 1360, the electricity consumption per month has increased from 650,216 to 951,907 kWh in 15 years. Nearly 50% rise in the consumption contributes more to the emission. This is found to be exclusively due to the decrease in efficiency of the motors. Hence, the reasons for inefficiency needed to be explored.

Low efficiency was found due to the poor maintenance of the motor and power transmission system, which leads to overheating of the motors and weakening of the winding capacity. They were also not protected from the environment, which had led to lots of corrosion of parts. In many instances, improper alignment of the shafts, bearings, and vibrations in the foundation was noted. This increases the friction in both associated drive transmission and motors, leading to a decrease in efficiency, load, and increase in power consumption. Lack of lubrication was also observed, which led to decreased efficiency and increased power consumption. All these result in decrease in efficiency and increase in power consumption.

Compressor efficiency was also found to be poor. This was due to contamination of air drawn, causing wear and tear in the compressor's moving parts. As a result, the efficiency of the compressor motor was decreased. Suitable air filters should have been provided at the suction end with sufficient capacity to separate dust and pressure drops. Their replacement is also necessary for efficient functioning. Compressors were found to operate at higher pressures. They should not be driven above their optimum operating pressures as this wastes energy and leads to excessive wear leading to further energy wastage. In addition, poor lubrication of the bearings and housings, use of local rewinding motors, air leakages, and inadequate insulation were found to prevail in the cluster.

Detailed meetings were held with managers/owners separately of the 20 units. Questions were posed about their awareness of standard motors and energy-efficient motors and the possible benefits of using

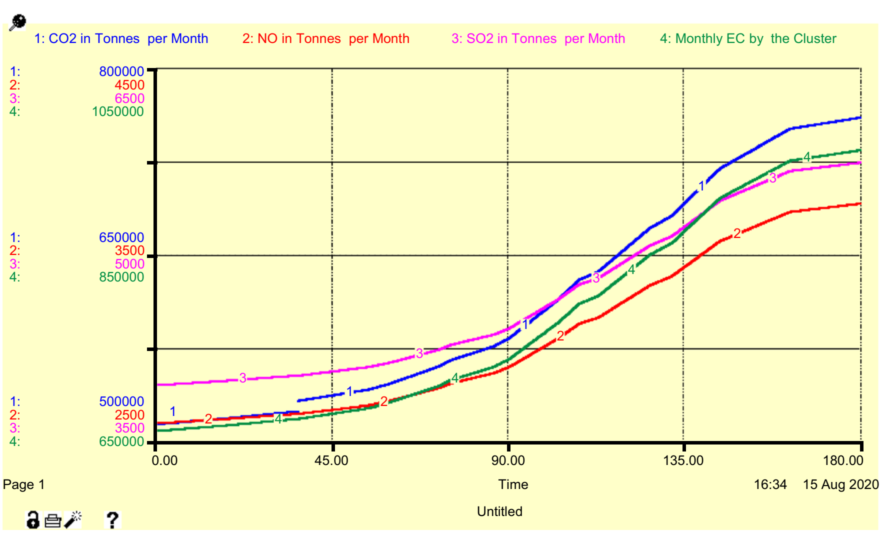

Fig. 8 Behavior of key variables over a period of 15 years

them. It was found, largely, that they are aware of the standard and energy-efficient motors and their benefits. But, they say that current solutions (way of repairing and maintenance) are working very well for them, which are "quick fixes" and "myopic." Their counter questions were as follows: What guarantees that the new machines won't fail? If they are so beneficial, why other washing units are not using the same? They want "someone to bell the cat."

The authors discussed how to convince these people or at least present to them theoretically the benefits and savings and the resulting pollution. We then gathered information from the market on energy-efficient motors, their life, maintenance, and cost and created three scenarios. For each scenario, the rationale is presented with literature support. This approach would alter the mental models, as shown in Fig. 1B. The three scenarios generated are:

- Replace all the motors with energy-efficient motors
- Replace all the motors with energy-efficient motors, install a solar plant of appropriate capacity
- Replace all the motors with energy-efficient motors and install a solar plant of proper capacity allowing for 1% CAGR in washing units

Scenario 1: replace all the motors with energy-efficient motors

It was found from the market survey that energy-efficient motors are developed based on better technology and have an average efficiency of 85% (conversion of electrical energy into mechanical energy). The benefits of such motors are found to be higher efficiency (Akbaba, 1999; Boglietti et al., 2008), less noisy (Enercom, 2020), less heating of the motors (Clean Energy 2015), reduced losses (Gutfleisch et al., 2011), and low maintenance and longevity (Energy Efficiency and Renewable Energy 2014). They enhance the overall productivity of the cluster (Worrell et al., 2003). Since the cluster uses motors of varying capacity, the average price of energy-efficient motors is computed as INR 10,000. Thus, the investment would amount to INR 13.60 million (17 × 80 × 10,000).

Two changes need to be incorporated into the model if all the motors are replaced with energy-efficient (EE) motors. There will be a change in the efficiency of the EE motors over 15 years. The investment in energy-efficient motors and the repayment of investment with interest. Banks, under various schemes, provide funds to SMEs, which is around 15% per annum (nationalized bank). The principal and interest are intended to be paid out of the savings resulting from reduced energy consumption by EE motors. The system dynamics model is simulated in Stella 9.1.4 software with dt at 0.1 month for a length of 180 months. The behavior of key variables is presented in Fig. 9.

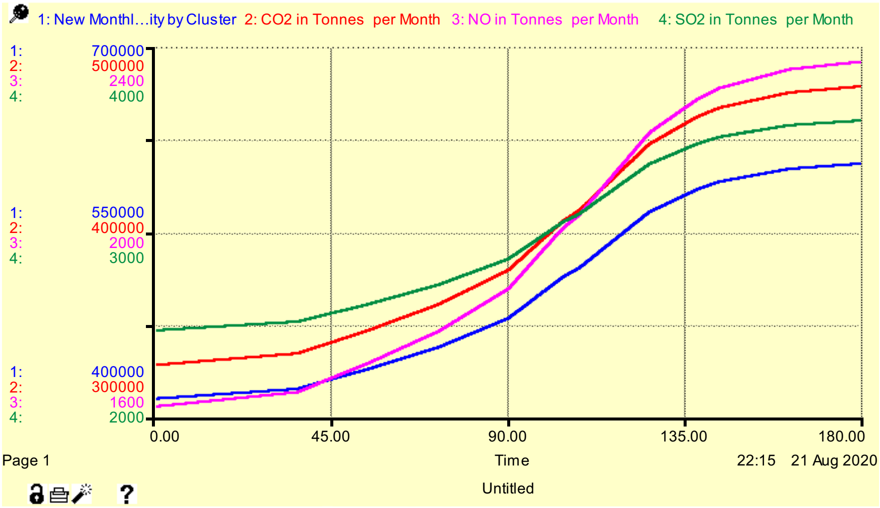

Fig. 9 Behavior of key variables for scenario 1

It can be seen from the figure that all the variables are increasing and then attaining stability. The electricity consumption by the cluster for 15 years is found to be 90,753,227 kWh, while the CO_2, NO, and SO_2 emissions over the same period are found to be 71,740,426; 354,845; and 539,982 t, respectively. With a reduction in energy consumption of 48,264,345 kWh, CO_2, NO, and SO_2 emission have reduced by 38,152,964; 188,714; and 287,173 t. Above all, the repayment on investment with interest is paid back in just 10 months. Computation of payment is explained below:

$$\textit{Monthly Energy Savings} = \textit{Monthly Energy Consumption by the Cluster} - \textit{Monthly Energy Consumption using EE motors by the Cluster} \quad (1)$$

$$\textit{Monthly Payment} = \textit{Monthly Energy Savings} * \textit{Energy Charges per Unit} \quad (2)$$

Scenario 2: replace all the motors with energy-efficient motors and install a solar plant of appropriate capacity

The industrial cluster is in a hot place where summer's average maximum temperature ranges between 42 and 45 °C. The mean year sunshine hour is 2698 h which is the highest in Karnataka, and the average highest yearly mean temperature is 32.2 °C. The experts opine that, on average, 7 kWh of power per day can be generated from 1 kVA solar panel. The authors mulled over proposing installing a solar plant to cater to the requirement.

Renewable energy sources and technologies, such as solar energy, can solve the energy problems of developing countries like India (Sharma et al., 2012). India is planning to deploy 20,000 MW of solar power by 2022. Solar energy is sustainable and renewable; there is no worry that it will eventually be depleted (Görig & Breyer, 2016). It is a non-polluting, reliable, and clean energy (Kabira et al., 2018). Limitations of tapping this energy include high initial cost (Kar et al., 2016) and lack of awareness (Dixit et al., 2018). According to Kapoor et al. (2014), the Karnataka government is offering tax concessions, stamp duty, registration exemptions, and central excise and customs duty exemptions to encourage the installation of solar plants. Since the Government of India provides a subsidy for establishing the solar plant, it is estimated that INR 100 million is required for establishing a 2.5-MW plant. The energy requirement is computed assuming all the motors to be EE motors; their cost of INR 13.60 million has also to be added. An investment of INR 113.60 million has to be recovered along with interest on investment which is assumed to be 10% per annum (since Government provides subsidies and other concessions).

The simulation was done incorporating all the above-discussed parameters. The system dynamics model is simulated in Stella 9.1.4 software with dt at 0.1 month for a length of 180 months. The behavior of key variables is presented in Fig. 10.

The electricity consumption by the cluster over 15 years is found to be 90,753,227 kWh as found in scenario 1, which has resulted in a reduction in energy consumption of 48,264,345 kWh. The emission of pollutants from such policy has resulted in a clean environment due to no emission. CO_2, NO, and SO_2 emission have reduced by 109,893,390; 543,559; and 827,155 t respectively. The repayment on investment with compounded interest is paid in 52 months. Since the solar plants have a life of 25 years with a slight reduction in efficiency after 10 years, they can enjoy total free energy for another 248 months.

$$\begin{aligned} \textit{Solar Grid Capacity} &= \textit{Annual Energy Consumption}/\textit{Energy Generated per 1 kVA solar panel per Year} \\ &= 5416644/(7*365) \\ &= 2120 = 2.1MW \end{aligned} \quad (3)$$

Scenario 3: replace all the motors with energy-efficient motors and install a solar plant of appropriate capacity allowing for 1% CAGR in washing units

Since the market reached stability, allowing for the addition of 1% washing units was thought of due to the developments/improvements in the cluster. Since the units are increased, it was found that another 0.5-MW plant is required after 90 months. This calls for an additional investment of INR 30 million. The above parameters were incorporated, and the system

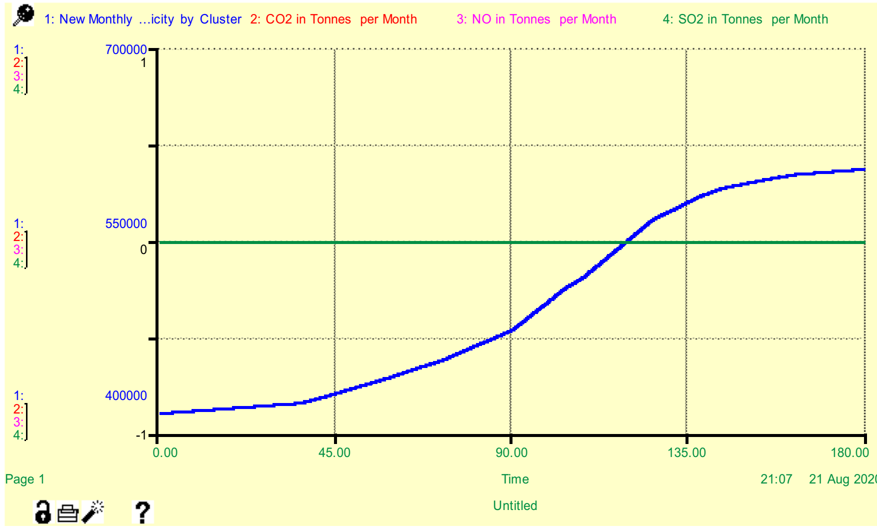

Fig. 10 Behavior of key variables for scenario 2

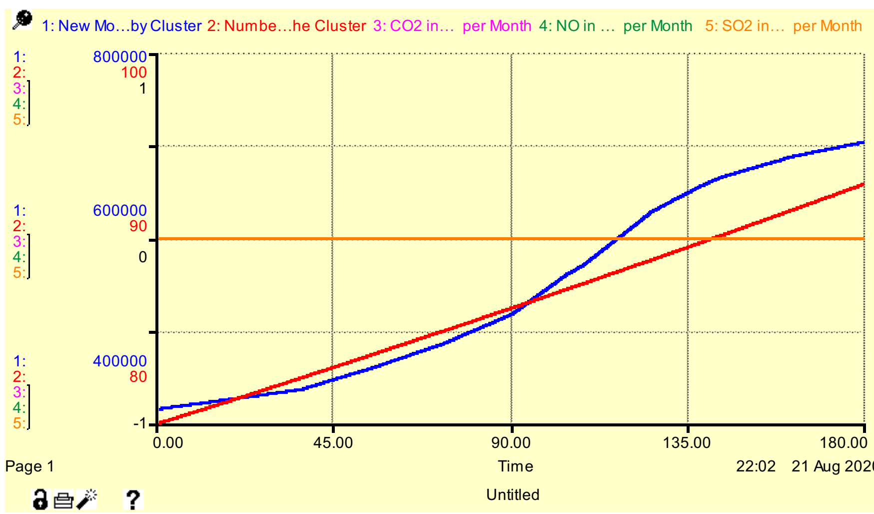

Fig. 11 Behavior of key variables for scenario 3

dynamics model is simulated in Stella 9.1.4 software with dt at 0.1 month for a length of 180 months. The behavior of key variables is presented in Fig. 11.

The number of washing units has reached a value of 93 at the end of 15 years. The total energy consumed by the cluster over 15 years was 98,507,210 kWh with no emissions of CO_2, NO, and SO_2. All this is clean energy. All the investments in energy-efficient motors, initial and second solar plants after 90 months are paid back with compounded interest in 54 months. As already mentioned, a solar plant has a life of 300 months; the cluster of 93 units can continue to use solar energy at no cost for the rest of 246 months.

The above analysis reveals the usefulness of the combined approach—efficient motors and clean and renewable energy sources. Scenario 1 proposes the replacement of all motors with energy efficient ones—this resulted in the reduction of the electricity consumption (by the cluster over 15 years) from 139,017,572 to 90,753,227 kWh. In scenario 2, solar power plant was proposed against the conventional non-renewable energy sources—this caused the emission of pollutants from such policy has to have reduced by 109,893,390; 543,559; and 827,155 t, respectively. Although the electricity consumption remained unchanged, it was a step towards a clean environment and sustainable practices.

Scenario 3 considers an increase at the rate of 1% CAGR in washing units, i.e., an increase in the number of units and its impact. As such, the electricity bill is higher but with lesser energy consumption (than conventional energy sources) and lower emission levels per output per unit washed.

Don't scenarios 1, 2, and 3 appear pragmatic and attractive? There may, however, be minor variations in cost considerations (maybe around 5%). Why have the people in the cluster not opted for these policies then?

Discussions

The results demonstrate four crucial managerial implications not identified in previous studies.

i. Using the right key performance indicators (KPIs) to enable sustainable decision-making.

Energy consumption is not a function of the number of devices but also energy consumed per device. Thus, as demonstrated in the model's base run, the electricity consumption per month increases by nearly 43.40% (from 650,216 to 951,907 kWh) in 15 years when existing (inefficient) machines are in use. However, the decision-makers fail to recognize the need for EE machines as they perceive the increase in consumption is due to enhanced production and corresponding increased charges. Thus, the appropriate KPI would be energy (E) consumed per unit output (O), i.e., $\frac{E}{O}$, and not absolute energy consumption or cost. These can come down when production or per unit charge drops. SMEs need to realize that energy efficiency is vital for sustainable development as it enhances competitiveness and minimizes environmental degradation (Costa-Campi et al., 2015).

ii. Preventive maintenance causes production loss in the short run but leads to optimal output and energy consumption in the long run.

The firms under study showed poor maintenance of the motor and power transmission system, lack of lubrication, improper alignment of the shafts and bearings, and vibrations in the foundation. They used re-wounded (more than two times) motors. In case of a busy schedule, even simple maintenance measures go unheeded. As such, machines suffered breakdowns and increased energy consumption. It was found from the discussion with managers that maintenance activities certainly reduce energy consumption and enhance the life of the motors. However, it calls for annual maintenance contract (AMC) with appropriate agency and one additional person to look after the system.

iii. Production targets and order fulfillment are necessary but not sufficient for long-term benefits. The use of energy-efficient machines yields higher financial returns. The returns are to be calculated not in terms of revenue fetched against investments alone made but should include the savings from reduced energy consumption.

The system dynamics model was simulated for three scenarios, and the results are presented in Table 3.

Table 3 Comparison of results for all the scenarios

Sl. no	Description	Base run	Scenario 1	Scenario 2	Scenario 3
1	Energy consumption by the cluster (kWh)	139,017,572	90,753,227	90,753,227	98,507,210
2	Electricity bill (INR)	903,614,215	589,895,974	0	0
3	CO_2 emission (t)	109,893,390	71,740,426	0	0
4	NO emission (t)	543,559	354,845	0	0
5	SO_2 emission (t)	827,155	539,982	0	0
6	Payback period (months)	–	10	52	54

In scenario 1, all the 1360 motors are replaced by energy-efficient motors at a total cost of INR 13.60 million. This has resulted in a decrease in energy consumption by 34.72% and a corresponding reduction in electricity charges and emissions. The energy cost savings outweigh the investment in EE motors in less than a year. EE motors are essential to optimize energy consumption (Bortoni et al., 2020). Naik and Bagodi (2021) demonstrated that EE motors (in place of traditional ones) decrease energy consumption by about 40% in Indian SMEs. Thus, the authors have met the first objective set for the study.

In scenario 2, all the 1360 motors are replaced by energy-efficient motors, and a solar plant of 2.5 MW capacity is installed. This calls for an investment of INR 100 million for solar plant installation and 15 years of maintenance and INR 13.60 million in energy-efficient motors. This has resulted in a decrease in energy consumption by 34.72% and zero pollution. This investment can be recovered with a compounded interest of 10% through energy savings in less than 5 years. Solar energy, among other renewable sources of energy, is a promising and freely available energy source for managing long-term issues in the energy crisis (Kannan & Vakeesan, 2016). INR 113.60 million is a considerable investment; hence, the cluster association through cooperative movement can easily establish the solar plant. Clarke et al. (2006) said that SMEs form an alliance and co-operate once a common objective is identified.

Application and use of renewable energy sources lead to the conservation of non-renewable energy sources. Non-renewable sources such as coal require millions of years to replenish. The amount of employment created in photovoltaic plant installation and maintenance is growing, thus contributing to job creation and GDP.

iv. An organization learns when it builds exogenous factors into its decision-making. That is, adapts to changing environment.

The causal loop diagram presented in Fig. 5 consists of only endogenous variables. There are no exogenous variables. Meaning there is no feedback from the external world that alters their policies regarding decision-making on the energy efficiency of the motors. This is a clear indication of the absence of learning regarding energy efficiency. Change in the mental model is necessary for double-loop learning (Forrester, 1971), altering the beliefs leading to policy change (Sterman, 2000). Hence, this cluster is not a learning organization, at least as far as energy efficiency is concerned.

The authors held 3-h discussion with 20 managers/owners. During the interaction, the causal loop diagram and the results of three scenarios were presented. Some of the learning disabilities, challenges, and limitations prevailing in the jeans washing cluster SMEs are mentioned below:

- SMEs are busy carrying on their routine work.
- Finance appears to be a serious issue with SMEs.
- Regular maintenance schedule is absent, and breakdown maintenance is the common feature.
- Managers/owners show no/little interest in learning (Morrison & Bergin-Seers, 2002), but learning enhances their business performance (Bagodi et al., 2021; Frank et al., 2012).
- Managers/owners are aware of the energy-efficient motors but have never adopted them. The decision-makers in SMEs are significantly risk aversive (Wüstermann, 2017).
- The absence of double-loop learning is due to the risk-aversive behavior.
- *Phantasmagoria* is a useful concept.
- Causal loop diagrams and simulation results help convey to SME managers the benefits of various policies. Causal loop diagramming allows researchers to generate and communicate theories tied to the data (de Gooyert, 2019).
- Managers/owners understand and learn when communication is made in their language.

The three-scenario analyses (*phantasmagoria*) with operational heads demonstrate that (i) SMEs are capable of double-loop learning and (ii) energy audits can provide the missing link between the feedback loop and the recipients' mental models. The audits and exercises explain the differences between single- and double-loop learnings.

Conclusions

Authors have carried out an energy audit in 20 jeans washing units, in a cluster of 80, in Karnataka, India. They have developed a system dynamics model and have carried out policy experimentation. They also had a detailed discussion with the owners/managers of these units.

Wrong practices such as poor maintenance, usage of re-wounded motors (more than twice), and continuous usage of traditional motors have led to the lower efficiency of the motors. This has led to the increase in the energy consumption and corresponding increase in energy cost by an amount of 43.40%. Standard motors are more efficient than traditional ones and energy-efficient motors are even more efficient.

Replacement of all the existing motors with energy-efficient motors require an investment of INR 13.60 million, INR 0.17 million per washing unit. This policy results in decrease in energy consumption by 34.72% and corresponding decrease in electricity charges and emission. Monthly decrease in electricity charges can be used to pay back the investment in less than a year. Further, this policy decreases their production cost and, hence, increase in their profit after 1 year.

As evident from the literature, solar energy is renewable, green, clean, and inexhaustible but demands a huge initial investment. An appropriate 2.5-MW solar plant requires an investment of INR 100 million for installation and maintenance for 15 years. This is an inevitable step to meet the promise made by Sri. Narendra Modi at climate change conference in November 2021. The investment in adoption of energy-efficient motors and usage of solar energy can be recovered in less than 5 years. This requires a co-operative movement and support from the appropriate government as these SMEs are facing financial difficulties. If the appropriate government appraises the benefits of energy-efficient motors and solar energy, and assures SMEs of hassle-free implementation of the schemes, the people at large can be benefited by zero pollution. The application of renewable energy sources also led to conservation of non-renewable energy sources.

No attention is paid to energy cost even though it contributes significantly to washing cost. There are no energy conservation or cost reduction strategies in place. These indicate that the single-loop learning is in action in these SMEs. It is evident from Table 3 that the benefits are immense if they have at least energy-saving policies. They need to be open minded and learn from other industrial sectors. They need to take calculated risks to reap up the benefits of technological advancement. Incentives and subsidies alone cannot bring in desired changes because a change in mindset and attitudes towards a long-term vision is required. Thus, it is impossible to bring in pertinent and vital changes unless their mental models are altered.

Limitations and directions for future work

The inferences are drawn based on the studies and experiences of only one cluster though it consists of 80 units; a detailed study was conducted in 20 units. More structured studies exploring the learning disabilities of Indian SMEs would throw more light on the realities. Studies are also required on the extent of implementation of government policies and schemes which would reveal the limitations in implementing them. Such studies will help the government appropriately design and devise the policies and schemes.

Author contribution VB: conceptualization, methodology, software, validation, formal analysis, investigation, writing original draft, writing review and editing, visualization.

DS: writing review and editing, supervision, and proofreading.

SN: survey and data acquisition.

Declarations

Conflict of interest The authors declare no competing interests.

Permission statement The words plant/s do not refer to living things. Humans only refer to workers. The authors/researchers, generally, use these terms.

Appendix

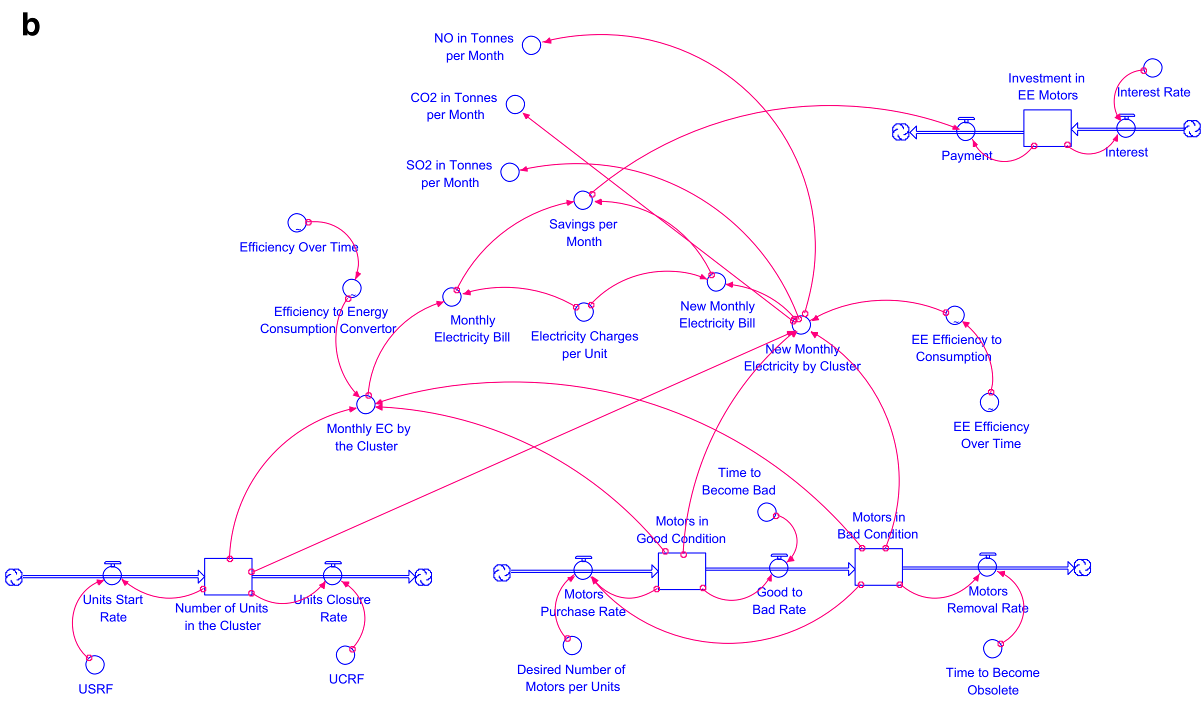

Fig. 12 Stock-flow diagram of the base run model

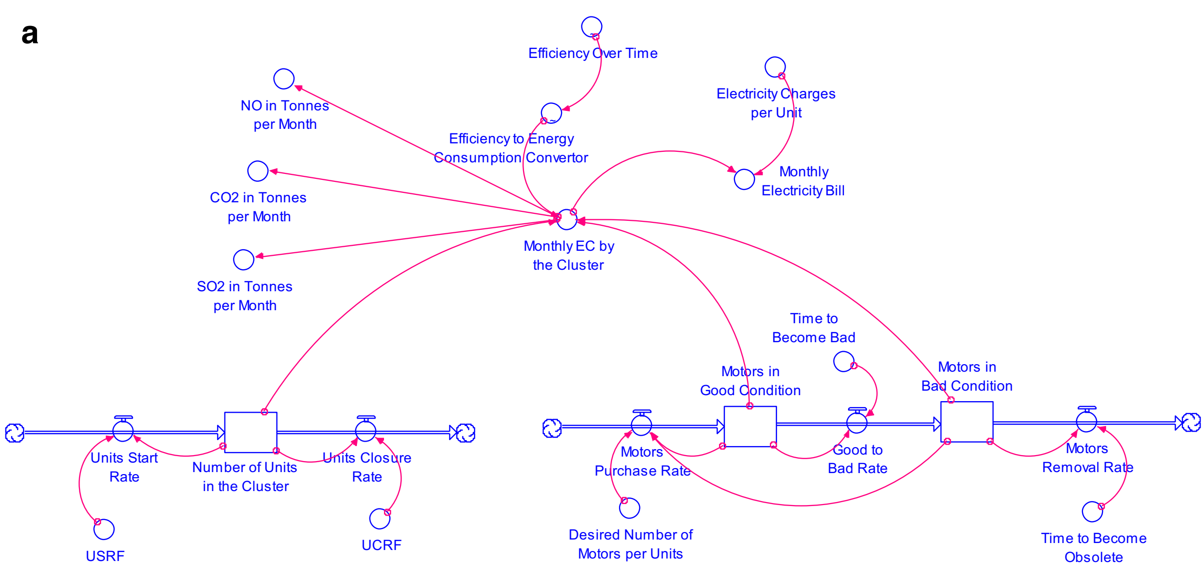

Fig. 13 Stock-flow diagram of the scenarios 1, 2, and 3

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