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ORIGINAL PAPER

Prediction of the resource-efficient potential of Turkish manufacturing industry: a country-based study

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Abstract

As an emerging country, there is a rapid industrial development and associated excessive resource consumption in Turkey. In this case, the dissemination of cleaner production activities based on the principle of minimum resource consumption and waste generation should be regarded as the priority target to ensure efficient use of the resources, enhance the manufacturing industry's competitiveness, and reduce environmental impacts. In this paper, the potential of resource efficiency in Turkish manufacturing industry was predicted. Input saving potential in each industry and aggregate manufacturing was predicted under three different scenarios: business-as-usual, realistic, and ideal. While we used industry saving rate obtained from the field surveys in business-as-usual scenario, we used (in)efficiency scores obtained from Stochastic Frontier Analysis (SFA) conducted for the entire manufacturing industry as well as for the five selected sectors and sub-sectors by using the firm-level panel data Turkish manufacturing from 2008 to 2012 together with the sectoral saving rates. The potential of resource efficiency is estimated for five sectors: (10) Manufacture of food products, (13) Manufacture of textiles, (20) Manufacture of chemicals and chemical products, (23) Manufacture of other nonmetallic mineral products, and (24) Manufacture of basic metals. Then, it is generalized to whole Turkish manufacturing industry. The calculations were performed in both monetary and quantitative terms for energy and water inputs but only in monetary terms for raw material inputs. It is estimated that the Turkish manufacturing industry's monetary-saving potential ranges from $8.8 billion/year to $14.5 billion/year based on the three scenarios specified for all inputs. In addition, according to the realistic scenario, 44.5% of total monetary-saving potential stems from SME savings (47.3% raw material, 41.8% energy, and 9.8% water). Besides, TR10 (Istanbul) and TR42 (Kocaeli, Sakarya, Düzce, Bolu, Yalova) regions have highest raw material and energy-saving potential, respectively. According to the realistic scenario, their share of the total saving value stood at 27% and 14%, respectively. Also, TR63 (Hatay, Kahramanmaraş, Osmaniye) and TR22 (Balıkesir, Çanakkale) regions have the highest water-saving potentials. To the best of our knowledge, this study is the first attempt in examining resource efficiency in the Turkish manufacturing industry in the broadest scope. Moreover, the methodology used in this work is said to be first and unique. We believe this methodology will open new avenues to the new researches both in Turkey and other countries.

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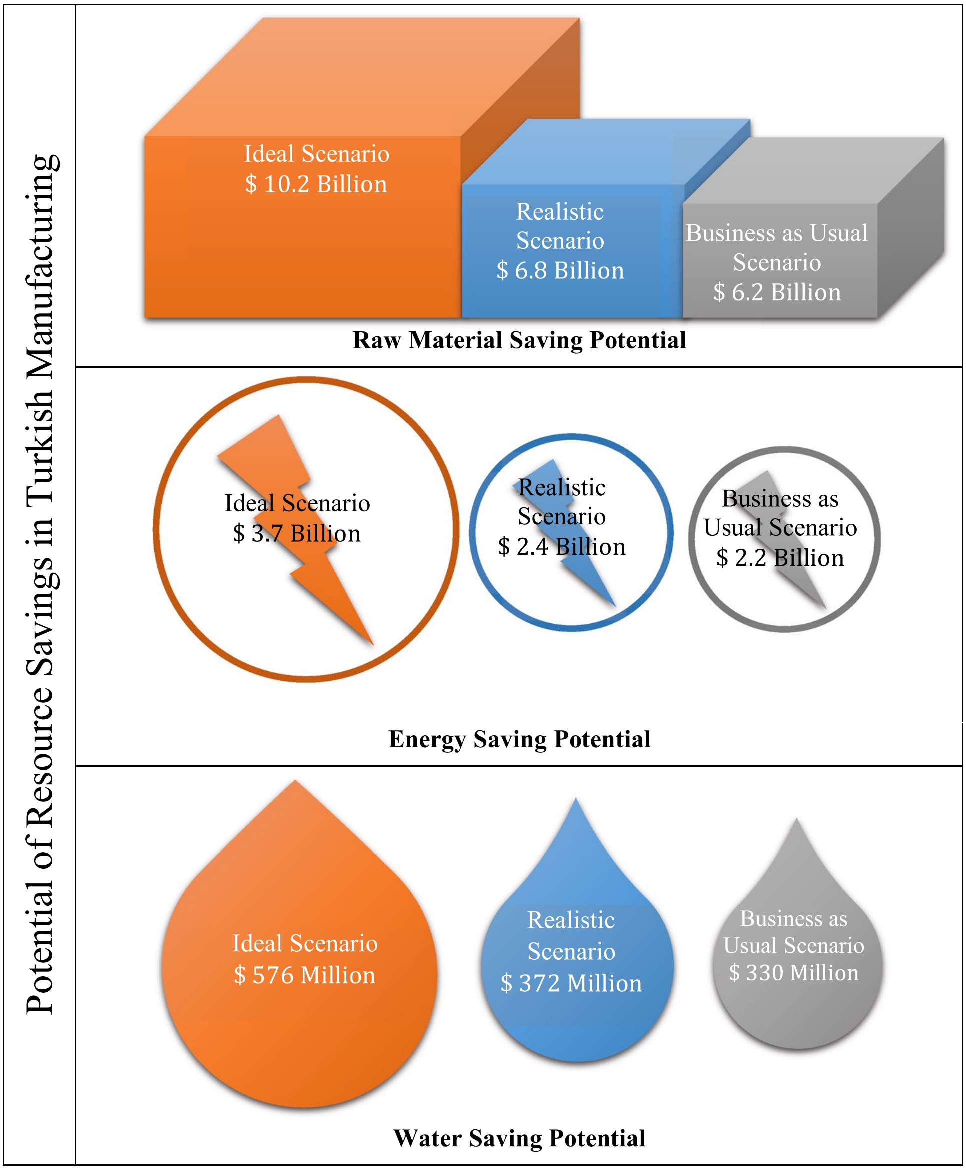
Graphical abstract



Keywords Resource-efficient potential · Cleaner production · Manufacturing industry · Environmental impact · Stochastic frontier analysis

Abbreviations

EC	European commission
EU	European Union
DEFRA	Department for Environment Food & Rural Affairs
UNIDO	United Nations Industrial Development Organization
SME	Small- and medium-sized enterprises
TOE	Tonnes of oil equivalent
TRY	Turkish Lira

List of symbols

$AIV_{it<1>1}$	Average investment value for investments with a payback period of less than 1 year and more than 1 year in the *i* sector at time *t*
$AS_{it<1>1}$	Average saving value for investments with a payback period of less than 1 year and more than 1 year in the *i* sector at time *t*

EFF_{ijt}	The efficiency score of the *j* business in the *i* sector at time *t*
EFF_{it}	The average efficiency level (on sector level) of the *i* sector at time *t*
e	Energy
IV_{it}	Investment value in the *i* sector at time *t*
$IV1_{it<1, >1}$	Investment value required to achieve savings of 1 TRY with the investments with a payback period of less than 1 year and more than 1 year in the *i* sector at time *t*
$IV_{it<1, >1}$	Sum of investments with a payback period of less than 1 year and more than 1 year in the *i* sector at time *t*
$NA_{it<1, >1}$	Number of applications of investments with a payback period of less than 1 year and more than 1 year
PBP_{it}	Payback period of investment in the *i* sector at time *t*
PS_{it}^{e}	Monetary savings of energy for any *i* sector at time *t*
PS_{it}^{r}	Monetary savings of raw material for any *i* sector at time *t*
PS_{it}^{T}	Total monetary savings for any *i* sector at time *t*
PS_{it}^{w}	Monetary savings of water for any *i* sector at time *t*
PS_{ijt}^{r}	Saving value obtained by the *j* business at time *t* for the raw material input
$PSQ_{ijt}^{e,w}$	The savings obtained by the *j* business in any *i* sector at time *t* for the energy and water inputs
$\overline{SR}_{it}^{r}$	Saving rate for any *i* sector and raw material
$\overline{SR}_{it}^{r,e,w}$	Raw material-, energy-, and water-saving rates in the *i* sector at time *t*
$\overline{SR}_{it}^{e,w}$	Saving rates for energy and water inputs in any *i* sector
$\overline{SR}_{it}^{w}$	Water-saving rate in the *i* sector at time *t*
$\overline{SR}_{mt}$	Raw material-saving rate in the other 19 sectors at time *t*
$\overline{SR}_{mt}^{e}$	Energy-saving rate in the other 19 sectors at time *t*
$\overline{SR}_{mt}^{w}$	Water-saving rate in the other 19 sectors at time *t*
$s1PS_{it}^{r,e,w}$	Monetary raw material, energy, and water savings for business-as-usual scenario
$s2PS_{it}^{r,e,w}$	Monetary raw material, energy, and water savings for realistic scenario
$s2PS_{TR}^{R,E,W,T}$	Raw material, energy, water, and total monetary savings of Turkish manufacturing industry for realistic scenario
$s2PSQ_{TR}^{E,W}$	Energy and water quantitative savings of Turkish manufacturing industry for realistic scenario
$s3PS_{it}^{r,e,w}$	Monetary raw material, energy and water savings for ideal scenario
$s2IV_{TR<1}^{R}$	Investments with a payback period less than 1 year for raw material for realistic scenario
$s2IV_{TR>1}^{R}$	Investments with a payback period more than 1 year for raw material for realistic scenario
$s2IV_{TR}^{R}$	Total investment value for raw material for realistic scenario
$sxPS_{it}^{elc}$	Monetary electricity savings of the *i* sector at time *t*
$sxPS_{it}^{f}$	Fuel-related monetary-saving potential
$sxPSQ_{it}^{E}$	Quantitative total energy savings of the *i* sector at time *t*
$sxPSQ_{it}^{elc}$	Quantitative electricity savings of the *i* sector at time *t*
$sxPSQ_{it}^{f}$	Quantitative fuel savings of the *i* sector at time *t*
$sxPSQ_{it}^{w}$	Quantitative water savings of the *i* sector at time *t*
TC^{c}	Unit toe cost for coal derivatives
TC^{p}	Unit toe cost for petroleum derivatives
TC^{ng}	Unit toe cost for natural gas
TC_{ijt}^{r}	Total raw material input cost of the *j* business at time *t* in any *i* sector
TC_{kjt}^{r}	Raw material costs of the *j* business in the other 19 sectors at time t
TC_{kjt}^{e}	Energy costs of the *j* business in the other 19 sectors at time t
TC_{kjt}^{w}	Water costs of the *j* business in the other 19 sectors at time t
TC^{elc}	Electricity unit toe cost
$TC_{ijt}^{r,e,w}$	Raw material, energy and water costs of the *j* business in the *i* sector at time *t*
TC_{ijt}^{w}	Water costs of the *j* business in the *i* sector at time *t*
TS_{it}	Total value of annual savings in the *i* sector at time *t*
$Q_{it}^{c,p,ng}$	Total consumption amounts of the fuels of coal derivatives, petroleum derivatives and natural gas at time t
Q_{ijt}^{w}	Water consumption amount used by the *j* business in any *i* sector at time *t*
$Q_{ijt}^{e,w}$	Energy or water amount used by the *j* business in any *i* sector at time *t*
Q_{it}^{tf}	Total fuel consumption of the *i* sector at time *t*
Q_{kjt}^{w}	Water consumption of the *j* business in the other 19 sectors at time t

q_{jt}	The monetary value of the production of the business *j* at time *t*
$\propto_{ijt}$	Efficiency coefficient
$\propto_{kjt}$	Efficiency coefficient of the *j* business in the other 19 sectors at time t
α_{it}^{c}	Consumption share of the *i* sector at time *t* within the *i* sector for coal derivatives
α_{it}^{p}	Consumption share of the *i* sector at time *t* within the *i* sector for petroleum derivatives
α_{it}^{ng}	Consumption share of the *i* sector at time *t* within the *i* sector for natural gas
β	The parameter vector to be estimated
β_{ijt}	Potential efficiency coefficient of the firm in the ideal scenario
x_{jt}	The inputs used in the production of the business *j* at time *t*
u_{jt}	(In) efficiency of the business
v_{jt}	Error term
w	Water

Introduction

Scarce and valuable resources such as raw materials, energy, and water constitute the essential inputs of any economy. The sustainability of life and the economy is directly linked to the resources since their use has effects both on the ecology and on the economy. The use of resources not only leads to pressure on natural resource and affects the environment but also influences national and international trade balances and market equilibriums. The expansion of international commodity markets raises price volatility along with unsustainable, inefficient use of resources in many markets while increasing global population and wealth levels also boost the demand for resources and their prices. Between 1970 and 2017, the world population increased by 2.5 times, while industrial minerals' consumption increased by 376% and fossil fuel consumption increased by 142%. Energy prices increased by 40 times from 1960 to 2018 (World Bank 2018a, b; Materialflows 2018).

Nowadays, energy and energy policies are the main factors that determine the position of countries. By the year 2023, Turkey's main aim is to reduce the cost of energy production, to create minimum effect on ecosystem, and to use renewable energy sources with resource-efficient technologies under the lights of UNFCCC and Kyoto protocol (Incekara and Ogulata 2017). For several decades, Turkey has acknowledged the importance of preventing dangerous anthropogenic effects of the climate change. In this case, Turkey submitted its Intended Nationally Determined Contribution (INDC) in 2016 (UNFCCC 2016) after COP21 which was held in Paris. One of the major measurable highlights in Turkey's INDC is a reduction up to 21% in GHG emissions compared to the business-as-usual (BAU) scenario of the government. This decrease corresponds to have a CO_2 equivalent (CO_2e) emission level of 929 million tonnes (Mt) in 2030 (UNFCCC 2016; Kat et al. 2018). The reduction in greenhouse gas emissions is directly related to the increasing energy efficiency and conservation of natural sources. The analysis shows that global annual energy demand will boost by approximately 80% between 2010 and 2050, with 90% of this increase due to increased demand in developing countries (Berg et al. 2011). Therefore, the resource efficiency of developing countries will have significant impacts on both their economies and global welfare.

The rapid growth in population and economic development in Turkey caused an increase in energy demand (World Bank 2018c). Turkey is mostly dependent on fossil fuels (petroleum, natural gas, coal, etc.), which make up a significant part of energy consumption. Turkey supplies about 60% of its main energy consumption from imported energy sources. This percentage is 56% for electricity production. Turkey has experienced the fastest energy demand increase over the past decade among the OECD countries. Similarly, Turkey has recorded the world's second largest growth rate after China, with the highest demand increase in electricity and natural gas since 2002. The Turkish manufacturing industry consumed approximately 26.6 million tone energy in 2015 (General Directorate of Energy Affairs 2013). Turkey spent about $60 billion to meet energy demand in 2015, and this energy cost is constantly increasing. This payment is expected to reach about 70 billion USA dollars in 2017 if oil prices do not increase over $50–60 per barrel and gas prices do not rise to $500 per m^3. Currently, Turkey has significant quantities and a diverse range of renewable energy sources (Kok and Benli 2017). Taking this into consideration, renewable energy sources and resource-efficient production in all the industries can be considered as the most effective solutions for clean and sustainable energy in Turkey.

Like energy, water is also one of the most important elements of sustainable development. Water issues are multidimensional including economic, social, political, and cultural aspects. It is of great importance for Turkey that the development, management, use and protection of water resources should be planned in an integrated way taking into account all the economic and social needs (Yuksel 2015). Water management has recently become a major concern for Turkey like many countries. During the last century, consumption of water has been increased in the world. One of the greatest reasons is the unplanned industrial activities deteriorating the environment. In 2050, it is estimated that the number of people living in the regions affected by severe water stress will increase by 2.5 times to 3.9 billion (Berg et al. 2011). It is needed to avoid environmental pollution in the context of sustainable development. In this situation, the main aim is to manage and use the water resources efficiently (DSİ 2009; Yuksel 2015). According to "Turkey Water Report," total water consumption in Turkey increased 50.2% from 30.6% to 46.0 billion m^3 between 1990 and 2008 (Ministry of Environment and Forestry 2009). Projections show that total water consumption will increase almost threefold and become 112.0 billion m^3 between 2008 and 2030 (Ministry of Environment and Forestry 2008). During the same period (2008–2030), also industrial water consumption is expected to increase sharply from 5 to 22 billion m^3 (Ministry of Environment and Forestry 2009). Thus, serious measures should be taken and efficient techniques should be used in order to conserve water resources from depletion due to intensive industrial activities (Ulutas et al. 2011; Alkaya and Demirer 2015).

As mentioned above, because of these scarce and valuable natural resources, the researches based on resource efficiency are of great importance. But actually, the research available in the literature addressing quantitative resource efficiency including energy, water and raw material potential in manufacturing industry is very limited. Resource-efficient literature mostly consists of bibliometric studies (Linares and Labandeira 2010; Sorrell et al. 2011; Zhou et al. 2016; Tukker and Ekins 2019) and conceptual models that provide policy recommendations (Wilts and O'Brien 2019; Huysman et al. 2015; Gharfalkar et al. 2018; Kemp and Djik 2011). The next chapter focuses on studies measuring the resource-efficient potential in the world and in Turkey. In this study, it is aimed to predict quantitative and monetary resource-efficient potential for whole Turkish manufacturing industry at the level of both sectors and regions in terms of energy, water, and raw materials. Moreover, the methodology used in this work to predict the resource-efficient potential is the first and unique. We believe this methodology will open new avenues to the new researches both in Turkey and other countries.

Literature review

There are some studies examining resource-efficient potential in the economies. For instance, Lin and Long (2015) adopted the stochastic frontier analysis to study the average energy efficiency and saving potential of the chemical industry based on the assumption of the trans-log production function. Their results show that energy price and enterprise scale are conducive to the improvement of energy efficiency, while ownership structure has an opposite effect. The average energy efficiency in China was 0.6897 during 2005–2011. In addition, the energy efficiency of East China was higher than that of West and Central China, and the energy efficiency gap between the Eastern and the Western regions was widening. There is an opportunity of annual savings of 75 million dollars, 63 billion liters of water, and 300 gigawatts-hours of electricity, if only low-cost resource-saving activities are implemented in the textile sector in Bangladesh (Hasan and Leonas 2018). According to another study carried out for the UK manufacturing sector, it is found that in the last 10 years firms achieved an increase of 10–15% in non-labor efficiency, but still significant gains can be achieved. It is estimated that UK manufacturing industry has a potential of 10 million pounds profit, 300,000 jobs, and a reduction of 27 million tons of CO_2 gas emissions (Lavery et al. 2013). Similarly, according to the analysis conducted by the German Material Efficiency Agency (DEMEA) for the German manufacturing sector based on the case studies, small-scale firms have the material-saving opportunity to 11% of their annual turnover. Metal raw materials have the highest saving potential with an average of 72.000 euro per year (EIO 2012).

Du and Lin (2017) used a newly developed fixed-effects SFA model and applied that model to compare energy productivity growth across the world's 123 economies. As a result, on average there was 34.6% growth of energy productivity between 1990 and 2010, which was mainly driven by technological progress. Also, the developed countries achieved higher growth in energy productivity than the developing countries, and they leaded technological progress while the developing countries performed better in efficiency improvement. However, there is evidence that the technological superiority of the developed countries is eroding, and hence, the BRICS countries are to reduce the energy efficiency gap with the G7 countries (Chang et al. 2018) in the near future. Zhang and Kim (2014) preferred a multiple factor model on assessment of energy and environmental efficiency, which is more beneficial than partial indicators. According to Hu and Wang (2006) and Zhang and Kim (2014), every one of the inputs and outputs should be considered in a total-factor framework for energy efficiency measurements. For this purpose, they used Data Envelopment Analysis (DEA) because DEA provides a framework that combines multiple input and output factors for the efficiency analysis of decision-making units (DMUs). Hu and Wang (2006) analyzed China's regions in the scope of total-factor frame by selecting capital accumulation, labor and energy as input factors and solely GDP as an output factor. In another study, energy-efficient assessment is performed on regions of Japan in a total-factor view (Honma and Hu 2008). Xiaoli et al. (2014) analyzed total-factor energy efficiency (TFEE) index changes of Chinese industrial sectors both at regional and at sectoral levels considering capital, labor and energy as inputs and industrial value added as output. Since these studies contain only one output, Zhang and Kim (2014) remarked that economic or industrial production process is a joint activity. It employs energy and the remaining inputs (i.e., capital, labor) together and produces desirable outputs as well as undesirable outputs such as emissions and pollutants. Wang et al. (2013) improved DEA models for Chinese regions in order to examine energy and environmental efficiency considering desirable outputs, energy, and other inputs in a total-factor view. Goto et al. (2014) proposed a novel methodology for operational and environmental evaluation with undesirable outputs regarding manufacturing and non-manufacturing industries of 47 prefectures in Japan (Özkara and Atak 2015).

Hatfield-Dodds et al. (2017) used a novel multi-regional modeling framework in their study to develop projections to 2050 under existing trends and found that resource efficiency could provide pro-growth and pro-environment policies with global benefits of USD $2.4 trillion in 2050. Under existing trends, resource extraction is projected to increase 119% from 2015 to 2050, from 84 to 184 billion tonnes per annum, while greenhouse gas emissions increase 41%. Also, the co-integration method is applied to test the long-term equilibrium relationship among energy consumption and three explanatory variables during the period 1980–2013 by Lin and Chen (2018). They used an analysis method to forecast the energy demand of Chinese manufacturing industry (CMI). The results showed that if the government does not properly manage the economy, the energy demand of CMI would reach 2558.97 Mtce in 2020 and 2594.18 Mtce in 2030. On the contrary, if the government has attached importance to energy conservation and takes necessary actions, energy demand in the industry would reduce to 1113.79 Mtce by 2030. In addition, in Rohn et al.'s (2014) study, a preliminary literature and expert-based identification process, over 250 technologies, strategies, and products, which are regarded as resource efficient, were identified. Out of these, 22 subjects with high resource-efficient potential were selected. The analyses show that, to achieve substantial dematerialization, different measures need to be taken into account engaging key players to realize the potentials identified and to reveal further potentials. Shahbazi et al. (2017) had a bottom-up approach to identify material-efficient Key Performance Indicators (KPIs). In total, more than 3000 performance indicators were collected at seven manufacturing companies, of which only 80 indicators could be related to material efficiency. Dobes et al. (2017) remarked that material and energy costs represent about 50% of the operating costs incurred by European small- and medium-sized enterprises (SMEs). They tested a new comprehensive, needs-driven and quantitative diagnosis tool named the "EDIT Value Tool." This tool was piloted in eighteen manufacturing SMEs in six Central European countries. Test results show that the tool is effective in helping company personnel to identify the main weaknesses and the potentials for company improvements. The collection of quantitative and qualitative data helped the company personnel to develop new perspectives on how to monitor and to improve resource efficiency and sustainable manufacturing.

There are also some studies carried by some governmental organizations on this topic. One of them is the study carried out by Department for Environment Food & Rural Affairs (DEFRA) including case studies on waste, energy, and water efficiency in the sectors with high resource efficiency in the UK economy. The study identified saving potential values of £23 billion and £33 billion for investments with a payback period shorter than 1 year and those longer than 1 year, respectively (DEFRA 2011). The study which is directed by European Commission (EC) investigated resource efficiency in Europe and forecasted 20% energy savings (European Commission 2011). In addition, various case studies in sectors such as food and beverage production, metal production have been realized in a study that was directed by AMEC Environment and & Infrastructure and Bio Intelligence Service. The annual savings per business were stated to be in the range of €27,500–€424,000 across sectors in that study (AMEC 2013). Governmental organizations also undertake important tasks in funding projects on resource efficiency. DEFRA assigned £5 million to support innovative resource-efficient operations over the period of 2005–2008. The supports enabled £25 million resource efficiency by the end of 2008 (Mattson et al. 2010). In Turkey, Ministry of Energy and Natural Resources support the firms' projects aiming at increasing energy efficiency. From 2009 to present, 35 projects were funded with a budget of TRY 2, 2 million. With the implementation of these projects, an annual saving of 25,702 toe energy and TRY 22 million were achieved. Currently, 34,529 toe energy and TRY 46.42 Million monetary savings are expected from 157 projects funded by MENR (MENR 2013). Similar activities such as funding resource-efficient projects, providing trainings and consultancy services[1] are being carried out by the Resource Efficiency Agency of Germany.

In Turkey, the efforts in measuring resource efficiency and/or potential resource savings have especially focused on energy consumption for many years. Turkey, in fact, has a significant saving potential due to the fact that the level of Turkey's energy efficiency is lower than the OECD average (Akal 2016). In this framework, both private and public institutions have conducted relevant studies and audits. A project was carried out by an energy efficiency consultancy firm to reveal the energy-saving potential in Turkey as well as raise the awareness of energy efficiency, identify cleaner production options, and determine savings and investment potentials. Accordingly, energy audits were conducted in 96 buildings

[1] https://www.ressourceneffizienz.de/ressourceneffizienz/startpage-en.html.

and enterprises between 2010 and 2011. The study concluded that investments worth \$192,400 for 96 facilities would lead savings of \$127,000 per year, resulting in a payback period of 1.5 years (Karabal 2012). Another study was conducted by the World Bank. Manufacturing and construction industries were selected in the study because of their high shares in total consumption, which are 39% and 30%, respectively. Finally, the manufacturing industry's energy-saving potential was calculated as \$3 billion based on international benchmarking practices carried out by the General Directorate of Renewable Energy and a private consulting company. The specialists calculated energy-saving potential considering market conditions, production lines as well as process inputs and outputs in the sub-sectors. The survey with 19 enterprises in the iron and steel, paper, cement, and textile sectors showed that a \$219 million investment would lead to an energy-saving potential of \$178 million per year (World Bank 2010). Turkish economy has a two-sided problem in energy efficiency: Turkish economy not only suffered from the inefficient use of energy, but also there is a 5% reduction in the production of electricity (Kasap and Duman 2013). Nguyen et al. (2015) also showed that total factor productivity of Turkish manufacturing industry would have increased by 78% if the resource misallocation problem in the sector is diminished.

In summary, although there are some studies on energy efficiency and other resources, there is no country-based study investigating both quantitative and monetary resource-efficient potentials for manufacturing industry at the level of sectors and regions. This study will thereby fill this gap by both developing a methodology to analyze the potential savings at the sub-sector and manufacturing industry level of Turkey and estimating this potential quantitatively. To achieve this target, resource-efficient potential was calculated in monetary terms for raw material inputs, and both in monetary and quantitative terms for energy and water inputs. Thereafter, the potential was assessed and generalized to the Turkish manufacturing industry.

Methodology

This study involves essentially two main stages: The first is the collection of the data used in the analyses. The second is to estimate quantitative and monetary potential savings of the resources. To predict the quantitative and monetary potential savings of raw materials, energy, and water used in Turkish manufacturing industry, we first needed a saving rate because we know exactly how much a firm uses raw materials, energy and water in production from Turkish Statistical Institute's firm-level confidential data. Turkish Statistical Institute collects data from all the firms employing 19 + and 60% of the firms employing less than 20 employees in Turkish manufacturing. The other thing is the fact that saving potential might differ from firm to firm. In order to proxy this heterogeneity, we estimated (in)efficiency of each firm and used in prediction of resource-saving potential. At the end, we came up with three different scenarios: business-as-usual, realistic, and ideal.

Prioritization of sub-sectors

Throughout the study, required data were specified and national data sources were examined. Monetary calculations for all inputs and quantitative water calculations were done with the firm-level data (microdata) of Turkish Statistical Institute (Turkish Statistical Institute 2012). Quantitative energy savings were estimated on the basis of monetary-saving values with Energy Balance Tables (2013) of the Ministry of Energy and Natural Resources of Turkey (General Directorate of Energy Affairs 2013).

Initially, a prioritization study was conducted to determine the sub-sectors that best represent Turkish manufacturing industry. The sub-sectors were chosen by considering their resource-efficient potential, economic conditions, and environmental impacts. The sub-sectors were identified by creating a prioritization matrix together with the sector specialists and by using TurkStat's firm-level data. The selected sub-sectors are presented in Table 1.

Data collection

In order to collect the data to be used in the analysis, we first prepared a questionnaire to be used in the surveys with the enterprises. This questionnaire includes questions about the type and cost of technology implemented by the firm in order to increase resource (material, energy, and water) efficiency. In Part A of the questionnaire, business-specific information was requested to reveal the structure of the businesses in the identified sectors. In Part B, the aim was to collect data on the businesses' current production processes and resource utilization. In this context, the enterprises received questions about their total output, the values of their products, energy consumption, the amounts of water and raw materials, and the costs of these resources. In Part C, we collected data on benefit and cost indicators of resource efficiency (input, waste minimization and waste recovery) activities undertaken by businesses in the last 5 years. In this section, we aimed to understand whether the businesses carried out any activities to improve their resource efficiency. Their relevant savings were calculated if they implemented any activities/investments. Part D examined the environmental impacts of production activities. Finally, Part E looked at whether they plan to carry out any resource-saving improvement/investment in the next periods.

The enterprises were not selected randomly. A workshop was organized with participation of the experts from

Table 1 Selected sub-sectors

Sectors NACE Rev.2	Sector name
10	Manufacture of food products
10.1	Processing and preserving of meat and production of meat products
10.7	Manufacture of bakery and farinaceous products
10.8	Manufacture of other food products
13	Manufacture of textiles
13.3	Finishing of textiles
13.9	Manufacture of other textiles
20	Manufacture of chemicals and chemical products
20.1	Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic rubber in primary forms
20.4	Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations
23	Manufacture of other nonmetallic mineral products
23.3	Manufacture of clay building materials
23.5	Manufacture of cement, lime and plaster
24	Manufacture of basic metals
24.1	Manufacture of basic iron and steel and of ferroalloys

Table 2 The number of surveys provided on the basis of sub-sectors

Sectors NACE Rev.2	Sector name	Number of enterprises where surveys and onsite visits were conducted	Number of surveys obtained	Number of surveys evaluated
10	Manufacture of food products	32	31	22
13	Manufacture of textiles	36	29	27
20	Manufacture of chemicals and chemical products	32	23	18
23	Manufacture of other nonmetallic mineral products	38	35	30
24	Manufacture of basic metals	28	18	11
Total		166	136	108

the sectors and the unions/associations. The enterprises that implement the best available techniques and undertake improvements to enhance resource efficiency regardless of whether they required investments were taken into account. In addition, the enterprises comprising the sample were divided into small (< 50 employees), medium (49 < employees < 250), and large (> 249 employees) for each sub-sector according to their sizes. The main reason for separating the surveyed enterprises by their sizes is that both the investment size and the saving potential change in line with the business size.

We then conducted interviews and onsite visits with the enterprises. The data were collected through surveys and sector-specific checklists. In the surveys, business-specific information was requested to reveal the structure of the businesses in the identified sectors. The aim was to collect data on the businesses' current production processes and resource utilization. We collected data on benefit and cost indicators of resource-efficient activities undertaken by businesses in the last 5 years. We also tried to examine the environmental impacts of production activities.

The surveys and checklists from the enterprises were primarily evaluated in terms of their content and reliability. Surveys regarding the accuracy of which were not convincing were not taken into account. As part of the project, surveys and onsite visits were carried out in 166 facilities. However, 136 facilities submitted the surveys. Of these surveys, 28 were not used due to data deficiency. At the end, a total of 108 surveys were used in estimating the resource-saving potential (Table 2).

Saving potential calculation method

Efficiency analysis

In this part of the study, the factors determining the (in) efficiency of the enterprises operating in the Turkish manufacturing industry were examined by using the Stochastic Frontier Analysis (SFA). SFA defines inefficiency as a deviation from the efficient production limit. This deviation is expressed with a compound error term. This compound error term equals the sum of an error term with normal distribution and "inefficiency" term with an asymmetric distribution. The most general form of the production function model for panel data is given in Eq. 1 (Battase and Broca 1997; Battese and Coelli 1995; Coelli et al. 2003; Dudu and Kılıçaslan 2009).

$$q_{jt} = f\left(x_{jt}, \beta\right)\exp\left(v_{jt}u_{jt}\right) \tag{1}$$

Here, these symbols has the following definitions

q_{jt}: the monetary value of the production of the business j at time t

x_{jt}: the inputs used in the production of the business j at time t

β: the parameter vector to be estimated

v_{jt}: error term

u_{jt}: (in) efficiency of the business

Error terms (v_{jt}) are assumed to be normally distributed and independent of the efficiency term (u_{jt}). On the other hand, the efficiency term has a semi-normal distribution always taking a value greater than zero. The econometric representation of the trans-logarithmic production function is given in Eq. 2.

$$\begin{aligned} \ln q_{jt} = \beta_0 + \sum_{k=1}^{K} \beta_k \ln x_{kjt} + \sum_{k=1}^{K} \eta_k \left(\ln x_{kjt}\right)^2 \\ + \frac{1}{2} \sum_{m \neq 0} \sum_{s=1}^{K} \theta_m \ln x_{mjt} \ln x_{sjt} - u_{jt} + v_{jt} \end{aligned} \tag{2}$$

TurkStat implements a full-count method for the enterprises with 20 and more employees. Because the sampling method was applied to the enterprises with 19 and fewer employees and the possibility of being included in sampling by random selection are quite low each year, it is hardly possible to observe these enterprises in the panel data structure. Therefore, we excluded these enterprises with 19 or fewer employees in the estimated models to keep the panel structure of the data. The econometric estimations in this study were made with FRONTIER 4.1 © program. Some of the variables used in estimated models are: output (q), labor (L), capital (K), raw material (R), business size, profit margin, contracted input and output, market share, etc.

All the monetary variables used in the analysis were made real by using sector-specific price indices of four-digit level of NACE Rev.2. The SFA was conducted for the entire manufacturing industry as well as for the five selected sectors and sub-sectors by using the panel data from 2008 to 2012.

Calculation of saving rates for inputs

Potential saving rates were calculated on the basis of the saving data obtained from 108 surveys. Monetary values were used in the calculation of raw-material-saving rates due to the difficulties in collecting the quantitative data on different raw materials and converting them into the same unit. Accordingly, the sector saving rate for any i sector and raw material input is calculated according to the ($\overline{\boldsymbol{SR}}_{\boldsymbol{it}}^{\boldsymbol{r}}$) Eq. 3.

$$\overline{\mathrm{SR}}_{it}^{r} = \frac{\sum_{j=1}^{J} \mathrm{PS}_{ijt}^{r}}{\sum_{j=1}^{J} \mathrm{TC}_{ijt}^{r}} \quad r = \text{raw material} \tag{3}$$

In Eq. 3, PS_{ijt}^{r} stands for the saving value obtained by the j business at time t for the raw material inputs in any i sector, whereas TC_{ijt}^{r} represents the total raw material input cost of the j business at time t in any i sector.

The saving rates for water and energy inputs were calculated quantitatively. The sector-specific *saving rates* ($\overline{\boldsymbol{SR}}_{\boldsymbol{it}}^{\boldsymbol{e,w}}$) for energy and water inputs in any i sector can be calculated as in Eq. 4.

$$\overline{\mathrm{SR}}_{it}^{e,w} = \frac{\sum_{j=1}^{J} \mathrm{PSQ}_{ijt}^{e,w}}{\sum_{j=1}^{J} Q_{ijt}^{e,w}} \quad e = \text{energy}, w = \text{water} \tag{4}$$

In Eq. 4, $\mathrm{PSQ}_{ijt}^{e,w}$ is the savings obtained by the j business in any i sector at time t for the energy and water inputs as a result of all the practices, whereas $Q_{ijt}^{e,w}$ represents the energy or water amount used by the j business in any i sector at time t.

The study developed a methodology to calculate also the hidden savings from waste, but they are not shared in this publication. For detailed information, please see the Project Summary Book (Karahan et al. 2017).

Determining saving potential for the selected sectors

Potential savings were estimated under three different scenarios using sectoral saving rates for each business. Only the saving rate was used for the business-as-usual scenario, whereas both efficiency scores at the business level and sectoral saving rates were used in the other two scenarios.

Table 3 presents the number of enterprises in the Turkish manufacturing industry where quantitative and monetary analyses were conducted. In total, the analyses are performed for 43,281 enterprises for raw material and energy inputs and 5723 enterprises for water inputs.

Table 3 Number of enterprises analyzed

Inputs	Small-scale business	Medium-scale business	Large-scale business	Total
Raw material and energy	33,633	8067	1581	43,281
Water	–	4501	1219	5723

Determining monetary-saving potential for the selected sectors

Table 4 summarizes the calculations of sectorial-level monetary savings raw materials, energy, water, and the total with respect to the three different scenarios. In the *business-as-usual scenario*, it was assumed that each business operating in the industry had a potential equal to the saving rate determined for that particular sector.

The *realistic scenario* takes into account the average efficiency of the sector together with the efficiency levels of the enterprises (see Table 4). The saving potential of the enterprises was assumed to be inversely proportional to their efficiency scores, and the ratio of the sector's average efficiency to the efficiency of the business was used to calculate the saving potential. The efficiency score (EFF_{ijt}) was known at the business level, but the efficiency coefficient ($\propto_{ijt}$) was unknown. The efficiency coefficient $\propto_{ijt}$ was proxied as the ratio of average sectoral efficiency to the firm's efficiency. EFF_{ijt} represents the efficiency score of the *j* business in the *i* sector at time *t*. On the other hand, EFF_{it} represents the average efficiency level (on sector level) of the *i* sector at time *t*.

In the *ideal scenario,* the saving potential of the enterprises was assumed to be inversely proportional to their efficiency scores considering the efficiency levels of the enterprises in the ideal scenario, but this time the ratio of full efficiency[2] to the efficiency of the business was used to calculate the saving potential. The equations used in sectorial-level quantitative savings are summarized in Table 5.

Determining quantitative saving potential for the selected sectors

Quantitative energy-saving potential The quantitative energy-saving values were calculated with unit costs in two ways: one for electricity and one for fuel, based on monetary-saving values. The unit (tonnes of oil equivalent) toe cost in the electricity-based saving estimations was calculated with the data from the surveys. The consumption share of each fuel type in the total fuel consumption was determined with the aggregation of fuels such as coal and its derivatives, petroleum and its derivatives and natural gas consumed in selected sectors and manufacturing industry. Quantitative fuel-based saving potential was estimated on the basis of monetary-saving values according to the unit toe prices obtained from fuel consumption shares and the surveys. Quantitative total energy savings are calculated by adding up the quantitative electricity savings and the quantitative fuel savings.

Quantitative electricity-saving potential ($\boldsymbol{sxPSQ_{it}^{elc}}$) was calculated by the dividing monetary electricity savings ($sx\mathrm{PS}_{it}^{\mathrm{elc}}$) by the electricity unit toe cost ($\mathrm{TC}^{\mathrm{elc}}$).

Quantitative fuel-saving potential ($\boldsymbol{sxPSQ_{it}^{f}}$) was estimated by multiplying the monetary-saving potential of the sector ($sx\mathrm{PS}_{it}^{f}$) by the share of consumption of each fuel (α_{it}^{c}, α_{it}^{p} and α_{it}^{ng}) and by dividing fuel unit toe cost (TC^{c}, TC^{p} and TC^{ng}). Toe costs of each fuel are calculated from surveys. $\alpha_{it}^{c,p,ng}$ is calculated by dividing total fuel consumption (toe) of the *i* sector at time *t* (Q_{it}^{tf}) by the total consumption amounts (toe) of the fuels of coal derivatives, petroleum derivatives and natural gas at time *t* ($Q_{it}^{c,p,ng}$).

Quantitative water-saving potential

Only large- and medium-sized enterprises were included in the analysis in the quantitative water-saving estimations. m^3 was used as water use unit in the calculations. A majority of enterprises in the manufacturing industry was found to use water at no cost based on the face-to-face interviews. However, the unit cost of water in monetary water-saving calculations was assumed as \$1.1/m^3 (in 2015 prices) on average. This value can vary based on the sectors and enterprises. Also the quantitative values, rather than monetary consumption and saving rate, were taken into consideration. Quantitative water-saving potential ($sx\mathrm{PSQ}_{it}^{w}$) was also calculated for all the three scenarios with the same assumptions used in quantitative energy-saving potential calculations. The equations used in sectorial-level quantitative savings are summarized in Table 5.

Generalization to the Turkish manufacturing industry

The saving potential values estimated for each input in each sector were added up to obtain the total saving potential value of the Turkish manufacturing industry for each input. Since the surveys were based on only five selected sectors, the saving potential of the remaining 19 sectors[3] was estimated separately. The saving potential calculated for each input at a sector level was also calculated for the other 19 sectors. The saving potential of aggregate manufacturing industry was estimated by summing the saving potential of the enterprises in 24 manufacturing sub-sectors. The monetary-saving potential estimated with 2012 nominal prices was converted

[2] 1: The full efficiency value was accepted as 1.

[3] (11); (12); (14); (15); (16); (17); (18); (19); (22); (25); (26); (27); (28); (29); (30); (31); (32); (33).

Table 4 Equations used in sectorial-level monetary savings

Inputs	Monetary savings		
	Business-as-usual scenario	Realistic scenario	Ideal scenario
Raw material	$s1PS_{it}^{r} = \sum_{J=1}^{J} TC_{ijt}^{r} * \overline{SR}_{it}^{r}$	$s2PS_{it}^{r} = \sum_{J=1}^{J} TC_{ijt}^{r} * \overline{SR}_{it}^{r} * \propto_{ijt}$	$s3PS_{it}^{r} = \sum_{J=1}^{J} TC_{ijt}^{r} * \overline{SR}_{it}^{r} * \beta_{ijt}$
		$\propto_{ijt} = \frac{EFF_{it}}{EFF_{ijt}}$	$\beta_{ijt} = \frac{1}{EFF_{ijt}}$
Energy	$s1PS_{it}^{e} = \sum_{J=1}^{J} TC_{ijt}^{e} * \overline{SR}_{it}^{e}$	$s2PS_{it}^{e} = \sum_{J=1}^{J} TC_{ijt}^{e} * \overline{SR}_{it}^{e} * \propto_{ijt}$	$s3PS_{it}^{e} = \sum_{J=1}^{J} TC_{ijt}^{e} * \overline{SR}_{it}^{e} * \beta_{ijt}$
		$\propto_{ijt} = \frac{EFF_{it}}{EFF_{ijt}}$	$\beta_{ijt} = \frac{1}{EFF_{ijt}}$
Water	$s1PS_{it}^{w} = \sum_{J=1}^{J} TC_{ijt}^{w} * \overline{SR}_{it}^{w}$	$s2PS_{it}^{w} = \sum_{J=1}^{J} TC_{ijt}^{w} * \overline{SR}_{it}^{w} * \propto_{ijt}$	$s3PS_{it}^{w} = \sum_{J=1}^{J} TC_{ijt}^{w} * \overline{SR}_{it}^{w} * \beta_{ijt}$
		$\propto_{ijt} = \frac{EFF_{it}}{EFF_{ijt}}$	$\beta_{ijt} = \frac{1}{EFF_{ijt}}$
Total	$s1PS_{it}^{T} = s1PS_{it}^{r} + s1PS_{it}^{e} + s1PS_{it}^{w}$	$s2PS_{it}^{T} = s2PS_{it}^{r} + s2PS_{it}^{e} + s2PS_{it}^{w}$	$s3PS_{it}^{T} = s3PS_{it}^{r} + s3PS_{it}^{e} + s3PS_{it}^{w}$

In all scenarios, TC_{ijt}^{w} was calculated by multiplying the amount of drawn water by the unit water cost (\$1.1/m3)

Here, the symbols has the following definitions

$s1PS_{it}^{r,e,w}$, $s2PS_{it}^{r,e,w}$, $s3PS_{it}^{r,e,w}$: monetary raw material, energy and water savings in the i sector at time t for business-as-usual scenario, realistic scenario and ideal scenario

$TC_{ijt}^{r,e,w}$: raw material, energy and water costs of the j business in the i sector at time t

$\overline{SR}_{it}^{r,e,w}$: raw material-, energy- and water-saving rates in the i sector at time t

into nominal prices of 2015 by using TurkStat's Domestic Producer Price Index (D-PPI) at the four-digit level of NACE Rev.2. Saving rates of unobserved sectors were assigned based on Classification of Manufacturing Industries by Orientation (factor use) (OECD 1992). In the calculation of saving rates of 19 sectors, the saving rates of these unobserved sectors were assumed to be the same for the sectors with the same orientations, i.e., we used the saving rate of food industry (observed sector) for the unobserved resource-intensive sectors (11–12, 17–19, 23). Factor usage classification for 24 sectors in the Turkish manufacturing industry is given in Table 6. The equations used in aggregate manufacturing industry-level estimations are given in Table 7.

Investments needed for tapping saving potential and payback period

Tapping saving potential of the selected sectors Payback period (PBP) is one of the important factors in investment decisions that increase productivity. The payback period shows the period in which the savings obtained thanks to be an investment will cover the cost of that particular investment. The payback period is calculated in Eq. 5 by dividing the total investment value by the annual savings expected as a result of the investment.

$$PBP_{it} = \frac{IV_{it}}{TS_{it}} \tag{5}$$

Here;IV_{it} represents investment value in the i sector at time t, while TS_{it} represents the total value of annual savings in the i sector at time t. On the other hand,PBP_{it} represents the payback period of investment in the i sector at time t.

The saving potential for investments with a payback period of less than 1 *year and more than* 1 *year* was calculated for each input according to each of the three scenarios in the mentioned sectors by multiplying the total monetary raw-material-saving value with the ratio of savings related to investments with a payback period of less than 1 year and more than 1 year. Explanations and investment value calculations in this section are made according to raw materials and realistic scenario to set an example. As part of the study, the calculations were made using the same methodology for all three scenarios and inputs. *The total investment value* was calculated by adding up the values of investments with a payback period of less than 1 year and more than 1 year. For detailed information, please see the Project Summary Book (Karahan et al. 2017).

Results and discussion

Depending on 108 surveys and national data, Turkish manufacturing industry's estimated saving rates in terms of raw material, energy and water are given in Table 8.

Although the percentage of raw-material-saving rates appears to be low in the manufacturing industry, the monetary value of such potential surpasses the energy- and water-saving potential as the raw material costs are of very high.

Table 5 Equations used in sectorial-level quantitative savings

Inputs	Quantitative savings		
	Business-as-usual scenario	Realistic scenario	Ideal scenario
Energy	$\mathrm{s1PSQ}_{it}^{\mathrm{elc}} = \frac{s1\mathrm{PS}_{it}^{\mathrm{elc}}}{\mathrm{TC}_{it}^{elc}}$	$\mathrm{s2PSQ}_{it}^{\mathrm{elc}} = \frac{s1\mathrm{PS}_{it}^{\mathrm{elc}}}{\mathrm{TC}_{it}^{\mathrm{elc}}}$	$\mathrm{s3}PSQ_{it}^{elc} = \frac{s1PS_{it}^{elc}}{TC_{it}^{elc}}$
	$\mathrm{s1PSQ}_{it}^{f} = \left(\frac{\mathrm{s1PS}_{it}^{f}}{\mathrm{TC}^{c}} * \alpha_{it}^{c}\right) + \left(\frac{\mathrm{s1PS}_{it}^{f}}{\mathrm{TC}^{p}} * \alpha_{it}^{p}\right) + \left(\frac{\mathrm{s1PS}_{it}^{f}}{\mathrm{TC}^{ng}} * \alpha_{it}^{ng}\right)$	$\mathrm{s2PSQ}_{it}^{f} = \left(\frac{\mathrm{s2PS}_{it}^{f}}{\mathrm{TC}^{c}} * \alpha_{it}^{c}\right) + \left(\frac{\mathrm{s2PS}_{it}^{f}}{\mathrm{TC}^{p}} * \alpha_{it}^{p}\right) + \left(\frac{\mathrm{s2PS}_{it}^{f}}{\mathrm{TC}^{ng}} * \alpha_{it}^{ng}\right)$	$\mathrm{s3PSQ}_{it}^{f} = \left(\frac{\mathrm{s3PS}_{it}^{f}}{\mathrm{TC}^{c}} * \alpha_{it}^{c}\right) + \left(\frac{\mathrm{s3PS}_{it}^{f}}{\mathrm{TC}^{p}} * \alpha_{it}^{p}\right) + \left(\frac{\mathrm{s3PS}_{it}^{f}}{\mathrm{TC}^{ng}} * \alpha_{it}^{ng}\right)$
	$\alpha_{it}^{c,p,ng} = \frac{Q_{it}^{c,p,ng}}{Q_{it}^{tf}}$	$\alpha_{it}^{c,p,ng} = \frac{Q_{it}^{c,p,ng}}{Q_{it}^{tf}}$	$\alpha_{it}^{c,p,ng} = \frac{Q_{it}^{c,p,ng}}{Q_{it}^{tf}}$
	$\boldsymbol{s1PSQ_{it}^{E} = s1PSQ_{it}^{f} + s1PSQ_{it}^{elc}}$	$\boldsymbol{s2PSQ_{it}^{E} = s2PSQ_{it}^{f} + s2PSQ_{it}^{elc}}$	$\boldsymbol{s3PSQ_{it}^{E} = s3PSQ_{it}^{f} + s3PSQ_{it}^{elc}}$
Water	$\mathrm{s1PSQ}_{it}^{w} = \sum_{J=1}^{J} Q_{ijt}^{w} * \overline{\mathrm{SR}}_{it}^{w}$	$\mathrm{s2PSQ}_{it}^{w} = \sum_{J=1}^{J} Q_{ijt}^{w} * \overline{\mathrm{SR}}_{it}^{w} * \propto_{ijt}$	$\mathrm{s3PSQ}_{it}^{w} = \sum_{J=1}^{J} Q_{ijt}^{w} * \overline{\mathrm{SR}}_{it}^{w} * \beta_{ijt}$

$sx\mathrm{PSQ}_{it}^{f}$: fuel-related quantitative saving potential in the i sector at time t

$sx\mathrm{PS}_{it}^{f}$: fuel-related monetary-saving potential in the i sector at time t

TC^{c}, TC^{p}, TC^{ng}: unit toe costs for coal derivatives, petroleum derivatives and natural gas fuels, respectively, for the relevant scenario

$\alpha_{it}^{c}, \alpha_{it}^{p}, \alpha_{it}^{ng}$: consumption share of the i sector at time t within the i sector coal derivatives, petroleum derivatives and natural gas fuels, respectively

Q_{it}^{tf} : total fuel consumption (toe) of the i sector at time t

$Q_{it}^{c,p,ng}$: total consumption amounts (toe) of the fuels of coal derivatives, petroleum derivatives, and natural gas at time t

$sx\mathrm{PSQ}_{it}^{w}$, : quantitative water savings in the i sector at time t

Q_{it}^{w} : water consumption amount (m^3) of the j business in the i sector at time t

$\overline{\mathrm{SR}}_{it}^{w}$: water-saving rate in the i sector at time t

Table 6 Factor usage distribution in 24 sectors of the Turkish manufacturing industry

Sector characteristic	Sectors NACE Rev.2	Sector name
Resource-intensive sectors	10	Manufacture of food products
	11	Manufacture of beverages
	12	Manufacture of tobacco products
	17	Manufacture of paper and paper products
	18	Printing and reproduction of recorded media
	19	Manufacture of coke and refined petroleum products
	23	Manufacture of other nonmetallic mineral products
Labor-intensive sectors	13	Manufacture of textiles
	14	Manufacture of wearing apparel
	15	Manufacture of leather and related products
	32	Other manufacturing
	33	Repair and installation of machinery and equipment
Specialized industrial sectors	21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
	25	Manufacture of fabricated metal products, except machinery and equipment
Scale intensive sectors	16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
	20	Manufacture of chemicals and chemical products
	22	Manufacture of rubber and plastic products
	24	Manufacture of basic metals
	29	Manufacture of motor vehicles, trailers and semi-trailers
	30	Manufacture of other transport equipment
	31	Manufacture of furniture
Science-based sectors	26	Manufacture of computer, electronic and optical products
	27	Manufacture of electrical equipment
	28	Manufacture of machinery and equipment n.e.c.

Source: OECD (1992)

Raw-material-saving potential

Natural resources are the assets of nations that should lead to their economic development. On the contrary, under certain circumstances, they create a difficult environment for development. From this point, the raw-material-saving potential is estimated in this study.

The total monetary raw-material-saving value estimated in the Turkish manufacturing industry ranges from \$6.2 to 10.2 billion/year according to the scenarios (Fig. 1). These values correspond to approximately 3–4.5% of the total raw material consumption in Turkish manufacturing industry according to the scenarios. It can be seen that 70% of the total raw-material-saving potential in the Turkish manufacturing industry can be obtained from the improvements that require investment. According to the scenarios, raw-material-saving value ranges from an average of \$144,300/year to \$236,453/year on a business basis in the Turkish manufacturing industry.

Similarly, the total investment required varies from \$5.9 billion to \$9.8 billion depending on the scenario. We observed that 70% of the total saving value that requires investment can be reached with investments that constitute 9.5% of the total investment with a payback period less than 1 year. However, investments with a payback period of more than 1 year have an average payback period of 4.2 years, while the payback period for all the investments stands at 1.4 years.

Figure 2 shows the monetary proportion of the Turkish manufacturing industry's total raw-material-saving potential that can be realized with improvements that do not require investments as well as the proportion that can be ensured thanks to investments with a payback period of less than 1 year and more than 1 year.

Raw-material-saving potential based on business size

If Turkish manufacturing industry's estimated total raw-material-saving values are analyzed according to business size, we see that a significant share of the potential is concentrated in large-scale enterprises (Fig. 3). Monetary-saving potential of the large-scale enterprises range from \$3.1 billion/year to \$5.2 billion/year according to the scenarios. However, the raw-material-saving value of small- and

Table 7 Equations used in aggregate manufacturing industry-level estimations

Inputs	Monetary savings Realistic scenario	Quantitative savings
Raw material	$\mathrm{s2PS}_{TR}^{R} = \sum_{i=1}^{\dot{I}}(\mathrm{s2PS}_{it}^{r}) + \sum_{k=1}^{K}\sum_{j=1}^{J} TC_{kjt}^{r}\overline{\mathrm{SR}}_{mt}^{r} * \alpha_{kjt}$	
Energy	$\mathrm{s2PS}_{TR}^{E} = \sum_{i=1}^{\dot{I}}(\mathrm{s2PS}_{it}^{e}) + \sum_{k=1}^{K}\sum_{j=1}^{J} \mathrm{TC}_{kjt}^{e}\overline{\mathrm{SR}}_{mt}^{e} * \alpha_{kjt}$	$\mathrm{s2PSQ}_{TR}^{E} = \left(\frac{\mathrm{s2PS}_{TR}^{elk}}{\mathrm{TC}^{elk}}\right) + \left(\frac{\mathrm{s2PS}_{TR}^{f}}{\mathrm{TC}^{c}} * \alpha_{TRt}^{p}\right) + \left(\frac{\mathrm{s2PS}_{TR}^{f}}{\mathrm{TC}^{p}} * \alpha_{TRt}^{p}\right) + \left(\frac{\mathrm{s2PS}_{TR}^{f}}{\mathrm{TC}^{ng}} * \alpha_{TRt}^{ng}\right)$
Water	$\mathrm{s2PS}_{TR}^{W} = \sum_{i=1}^{\dot{I}}(\mathrm{s2PS}_{it}^{w}) + \sum_{k=1}^{K}\sum_{j=1}^{J} \mathrm{TC}_{kjt}^{w}\overline{\mathrm{SR}}_{mt}^{w} * \alpha_{kjt}$	$\mathrm{s2PSQ}_{TR}^{W} = \sum_{i=1}^{\dot{I}}(\mathrm{s2PSQ}_{it}^{w}) + \sum_{k=1}^{K}\sum_{j=1}^{J} \mathrm{Q}_{kjt}^{w}\overline{\mathrm{SR}}_{mt}^{w} * \alpha_{kjt}$
Total	$\mathrm{s2PS}_{TR}^{T} = \mathrm{s2PS}_{TR}^{R} + \mathrm{s2PS}_{TR}^{E} + \mathrm{s2PS}_{TR}^{W}$	

$\overline{\mathrm{SR}}_{mt}^{r}$, $\overline{\mathrm{SR}}_{mt}^{e}$, $\overline{\mathrm{SR}}_{mt}^{w}$: raw material-, energy- and water-saving rates in the other 19 sectors at time *t*

TC_{kjt}^{r}, TC_{kjt}^{e}, TC_{kjt}^{w}: raw material, energy and water costs of the *j* business in the other 19 sectors at time *t*

α_{kjt}: efficiency coefficient of the *j* business in the other 19 sectors at time *t*

Q_{kjt}^{w}: water consumption of the *j* business in the other 19 sectors at time *t*

$\mathrm{s2PS}_{TR}^{R,E,W,T}$: raw material, energy, water and total monetary savings of Turkish manufacturing industry

$\mathrm{s2PSQ}_{TR}^{E,W}$: energy and water quantitative savings of Turkish manufacturing industry

medium-sized enterprises (SMEs) constitutes a significant share of 47%–50% according to the scenarios. For this reason, the SMEs should not be neglected due to their remarkable raw-material-saving potential. Our findings suggest that a large-scale business operating in the Turkish manufacturing industry can save an average of $2 million/year and $3.3 million/year of raw materials according to the scenarios. For SMEs,[4] these values range from $74,400/year to $119,900/year.

Energy-saving potential

Energy is one of the Turkey's most important developmental priorities. The level of development of an individual country is directly related to the economic and social levels. Energy is one of the most important factors that play an active role in achieving this level of development. In parallel with population growth, industrialization, urbanization, and technological developments in the world, energy demand is rapidly increasing. The amount of energy use is one of the important indicators of economic magnitude, quality of life and social development in developing countries (Kok and Benli 2017).

Like many other countries, energy is one of the most important resources after raw material in terms of saving potential in the Turkish manufacturing industry. The reason for this is that energy constitutes the highest cost after raw materials in total input cost.

The analyses show that the Turkish manufacturing industry's energy-saving value ranges from approximately $2.2 billion/year to $3.7 billion/year according to the three scenarios (Fig. 4). According to the scenarios, energy-saving value ranges from an average of 51,148 $/year to approximately 86,551 $/year on enterprise basis in the Turkish manufacturing industry. Approximately 49% of the monetary energy-saving potential and 77% of the quantitative energy savings result from fuel savings (Fig. 5).

These values correspond to approximately 17–28% of the total energy consumption (27.8 million toe/year) in the manufacturing industry according to the scenarios. On the other

[4] The average savings of SMEs on a business basis were calculated by dividing the sum of saving values of small- and medium-sized enterprises by the total number of small- and medium-sized enterprises.

Table 8 Saving rates

Sectors NACE Rev.2	Raw-material-saving rates (%)	Energy-saving rates (%)	Water-saving rates (%)
10	2.28	13.55	9.76
13	4.07	19.27	25.79
20	4.46	17.10	9.33
23	5.89	20.47	22.59
24	1.14	12.62	16.56
11	2.28	13.55	9.76
12	2.28	13.55	9.76
14	4.07	19.27	25.79
15	4.07	19.27	25.79
16	1.14	12.62	16.56
17*	2.99	15.64	15.36
18*	2.99	15.64	15.36
19	5.89	20.47	22.59
21+	2.80	9.70	12.95
22	1.14	11.12	16.56
25+	2.80	14.86	12.95
26+	2.80	14.86	12.95
27+	2.80	14.86	12.95
28+	2.80	14.86	12.95
29	1.14	12.62	16.56
30	1.14	12.62	16.56
31	1.14	12.62	16.56
32	4.07	19.27	25.79
33	4.07	19.27	25.79

The average saving rates of the sectors (10), (13), (20) and (24) were used for the sectors (17) and (18)

+The average saving rates of the sectors (20) and (24) were used for the sectors (21), (25), (26), (27), (28)

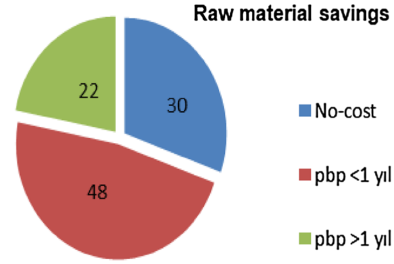


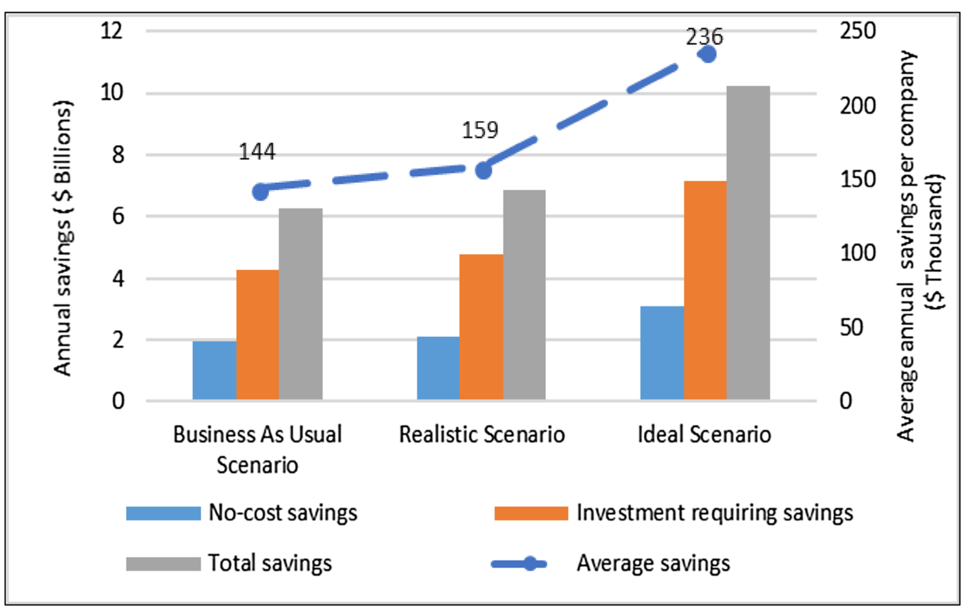
Fig. 2 Distribution of raw material savings according to investment requirement (realistic scenario)

hand, the estimated total energy-saving potential ranges from 4.6 million toe/year and about 7.8 million toe/year according to the scenarios.

According to the results, almost the entire saving potential (98%) can be achieved with improvements requiring investment. Similarly, the required investment amount ranges from \$4 billion/year to \$6.7 billion/year depending on the scenarios. However, investments with a payback period of more than 1 year have an average payback period of 3.8 years, while the average payback period for all the investments stands at 1.8 years.

Figure 6 shows the monetary proportion of the Turkish manufacturing industry's total energy-saving potential that can be realized with improvements that do not require investments as well as the proportion that can be ensured thanks to investments with a payback period of less than 1 year and more than 1 year.

Fig. 1 Raw-material-saving potential (monetary)



Note: The average saving data are shown by the secondary axis.

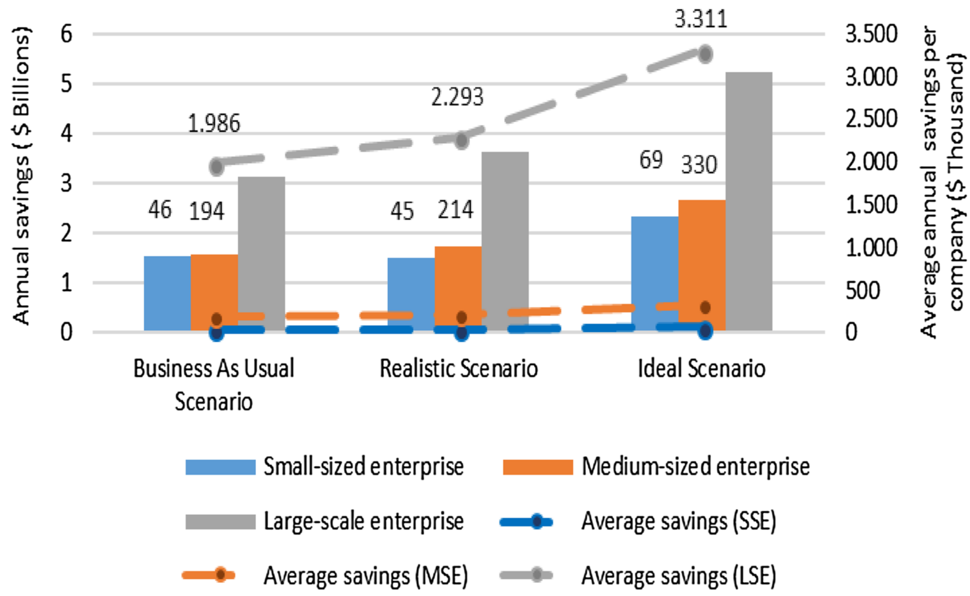


Fig. 3 Raw-material-saving potential based on business size (monetary)

Energy-saving potential based on business size

We see that large-scale enterprises play a significant role in energy savings when examining the energy-saving values according to the business size in the Turkish manufacturing industry (Fig. 7). Large-scale enterprises are estimated to have monetary energy savings of between \$1.3 billion/year and \$2.1 billion/year, and quantitative energy savings of between 2.6 million toe/year and 4.4 million toe/year. However, the quantitative energy saving of SMEs constitutes a significant amount, about 42%, of the total potential according to the scenarios. Then, it should be recognized that significant amounts of energy savings will be achieved in the manufacturing industry thanks to improvements to be made by the SMEs. We estimate that a large-scale business operating in the Turkish manufacturing industry can achieve an average of \$810,612/year and \$1.4 million/year of energy savings according to the scenarios. For SMEs,[5] these values range from \$22,319/year to \$38,488/year. When quantitatively assessed, these amounts range from 47 toe/year to 80 toe/year for SMEs according to the scenarios.

Water-saving potential

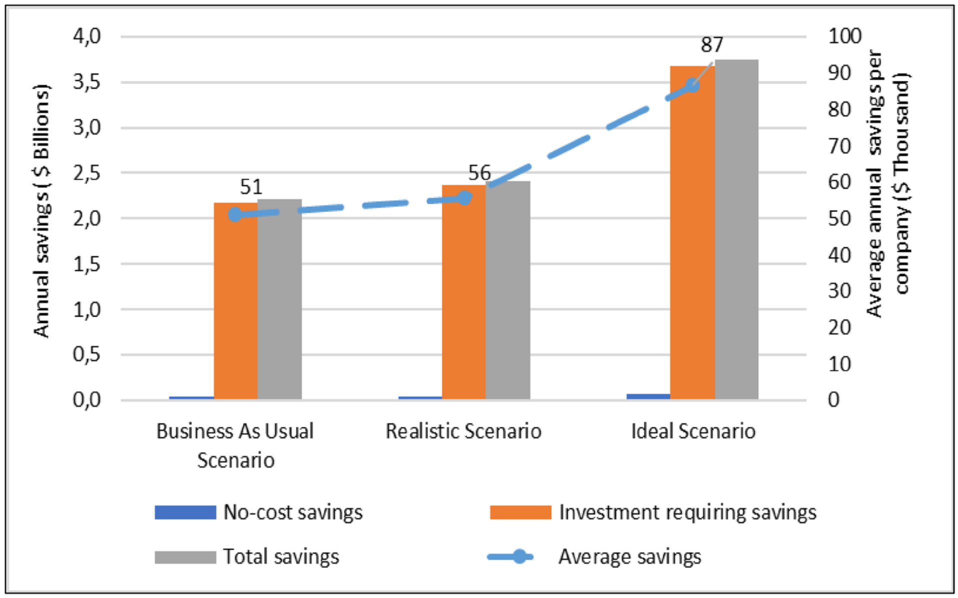
As an emerging economy, Turkey is currently witnessing a rapid industrial development and resource consumption. For instance, huge amounts of water are consumed by iron and steel and textile sectors. Therefore, the water-saving potential is taken into account in this study.

Figure 8 shows the total water-saving potential of the Turkish manufacturing industry. We see that water savings of approximately \$330.2 million/year and \$576.7 million/year can be achieved according to the scenarios. The water-saving potential was calculated on the basis of an assumed unit water cost of \$1.1/m^3, and it varies from 297.2 million m^3/year to 519 million m^3/year according to the scenarios. The main reason behind this low result is that many enterprises do not pay for the water they use in the production process. Naturally, a business shows a low saving tendency for an input if it does not constitute a cost for it. As unit price of water is considerably lower than raw material and energy unit prices, potential monetary water savings remain below the others. In addition, these values refer to only medium- and large-scale enterprises and correspond to 17–29% of the total water consumption amount in the manufacturing industry according to the scenarios. On the other hand, the Turkish manufacturing industry has an average monetary water-saving value of \$57,704/year–\$100,767/year and a quantitative water-saving amounts of 519 m^3/year–907 m^3/year on a business basis according to the scenarios.

One of the points to note is that 57% of the total water-saving potential in the Turkish manufacturing industry can be achieved with improvements that require investments, whereas 43% can be achieved with no-cost investments. Moreover, 78% of the savings that require investments can be achieved through those with a payback period of less than 1 year (5.6 months on average).

[5] The average savings of SMEs on a business basis were calculated by dividing the sum of saving values of small- and medium-sized enterprises by the total number of small- and medium-sized enterprises.

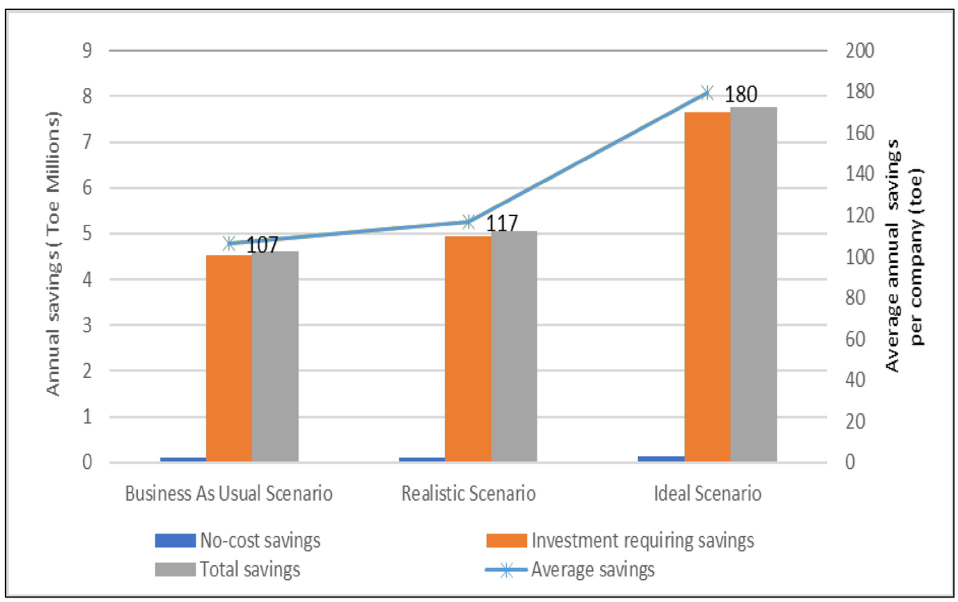
Fig. 4 Energy-saving potential



Note 1: The average saving data are shown by the secondary axis.

Note 2: The amount of energy savings is the sum of electricity and fuel savings.

(a) monetary



Note 1: The average saving data are shown by the secondary axis.

Note 2: The amount of energy savings is the sum of electricity and fuel savings.

(b) quantitative

Figure 9 shows the proportion of the total water-saving potential in the Turkish manufacturing industry that can be realized with improvements that do not require investments as well as the proportion that can be ensured thanks to investments with a payback period of less than 1 year and more than 1 year.

Water-saving potential on the basis of business size

According to the scenarios, around 89–91% of the total water-saving potential in the Turkish manufacturing industry is concentrated in large-scale enterprises (Fig. 10). However, it should not be ignored that small-scale enterprises could not be included in the analysis in the interpretation of results. We estimate that a large-scale business

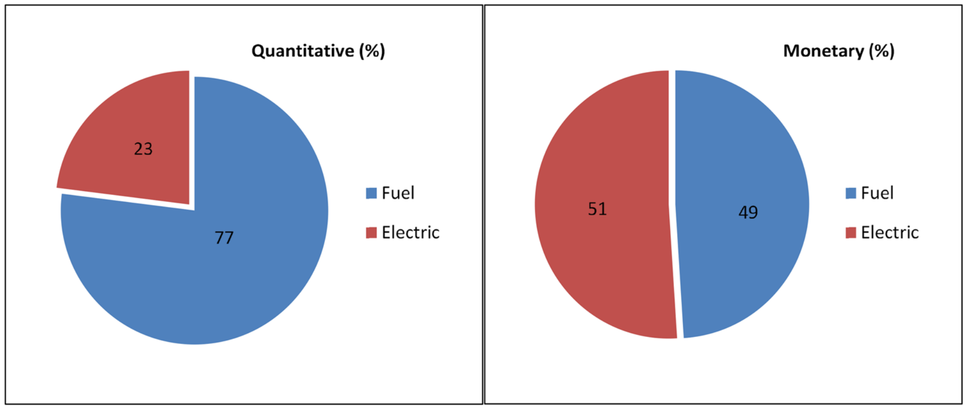
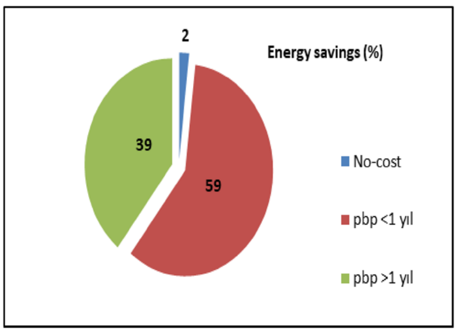


Fig. 5 Distribution of energy-saving potential (realistic scenario)



pbp: Payback period

Fig. 6 Distribution of energy saving according to investment requirement (realistic scenario)

in the Turkish manufacturing industry can achieve average monetary water savings of $245,281/year–$422,295/year as well as average quantitative water savings of 221,000 m^3/year and 380,000 m^3/year according to the scenarios.

Regional results

According to Fig. 11, TR10 (Istanbul) and TR42 (Kocaeli, Sakarya, Düzce, Bolu, Yalova) regions had highest total monetary potential in the Turkish manufacturing industry, respectively. These regions are followed by TR41 (Bursa, Eskişehir, Bilecik) and TR31 (Izmir), which have similar saving values.

Conclusion

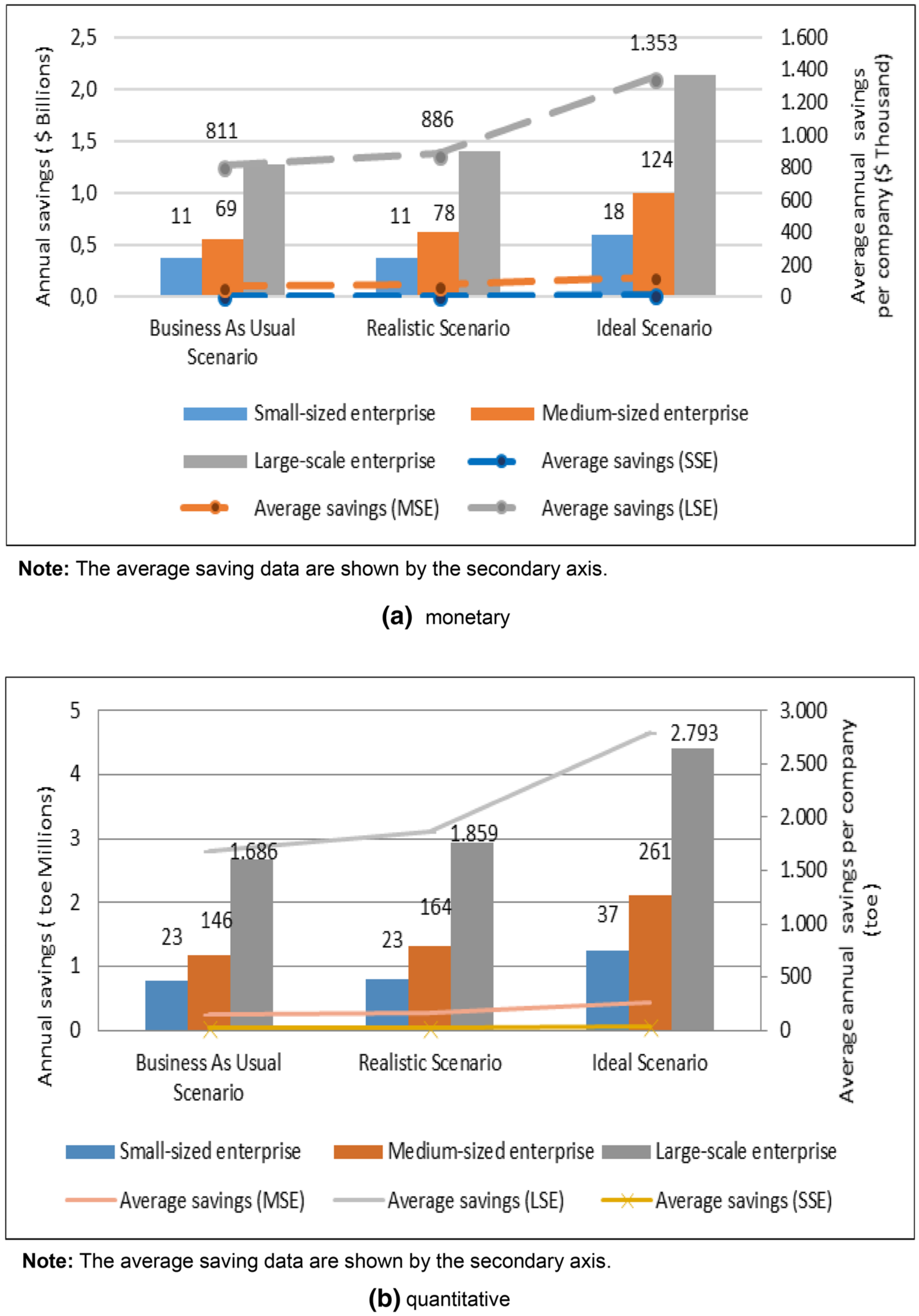
The main objective of this study is to determine the Turkish manufacturing industry's resource-efficient potential in monetary and quantitative terms for energy and water inputs, and in monetary terms for raw materials under three different scenarios in the five selected sectors and the aggregate Turkish manufacturing industry. The analyses are also conducted at a regional level within NUTS 26.

The results show that the total saving potential of all resources (raw material, energy and water) in Turkish manufacturing industry varies from approximately $8.8 billion/year to $14.5 billion/year according to the different scenarios. The raw-material-saving rates calculated by using the surveys in the selected sectors are lower than the saving rates of other resources and vary between 1.1% and 5.9%. However, nearly 71% share of the raw-material-saving potential of the total resource-saving potential draws attention to the high share of both raw material prices and costs in total input costs. Thus, even low raw-material-saving rates correspond to high amounts in monetary terms. TR10 (Istanbul) and TR42 (Kocaeli, Sakarya, Düzce, Bolu, Yalova) regions have highest total monetary potential in the Turkish manufacturing industry, respectively. These regions are followed by TR41 (Bursa, Eskişehir, Bilecik) and TR31 (Izmir), which have similar saving values. According to the realistic scenario, share of the total saving value of TR10 (Istanbul) and TR42 stood at 26.1% and 13.6%, respectively.

According to the results, most of the raw-material-savings potential is in the "Manufacture of chemicals and chemical products" "Manufacture of food products" and "Manufacture of textiles" sectors, respectively. It is seen that large-scale, medium-sized and small-sized enterprises account for 36–52%, 26–38%, and 21–27% of the total potential in the other selected sectors according to the scenarios. Besides, TR10 (Istanbul) region and TR42 (Kocaeli, Sakarya, Düzce Bolu, Yalova) region had approximately 27% and 14% of the total raw-material-saving potential, respectively. In addition, according to the realistic scenario, 47.3% of total monetary raw-material-saving potential stems from SME savings.

The total energy-saving potential predicted with the analyses on energy as another significant resource in the manufacturing industry ranges from around $2.2 billion/year to $3.7 billion/year according to the scenarios. This value constitutes approximately 25% of the total potential calculated for all the inputs in the manufacturing industry.

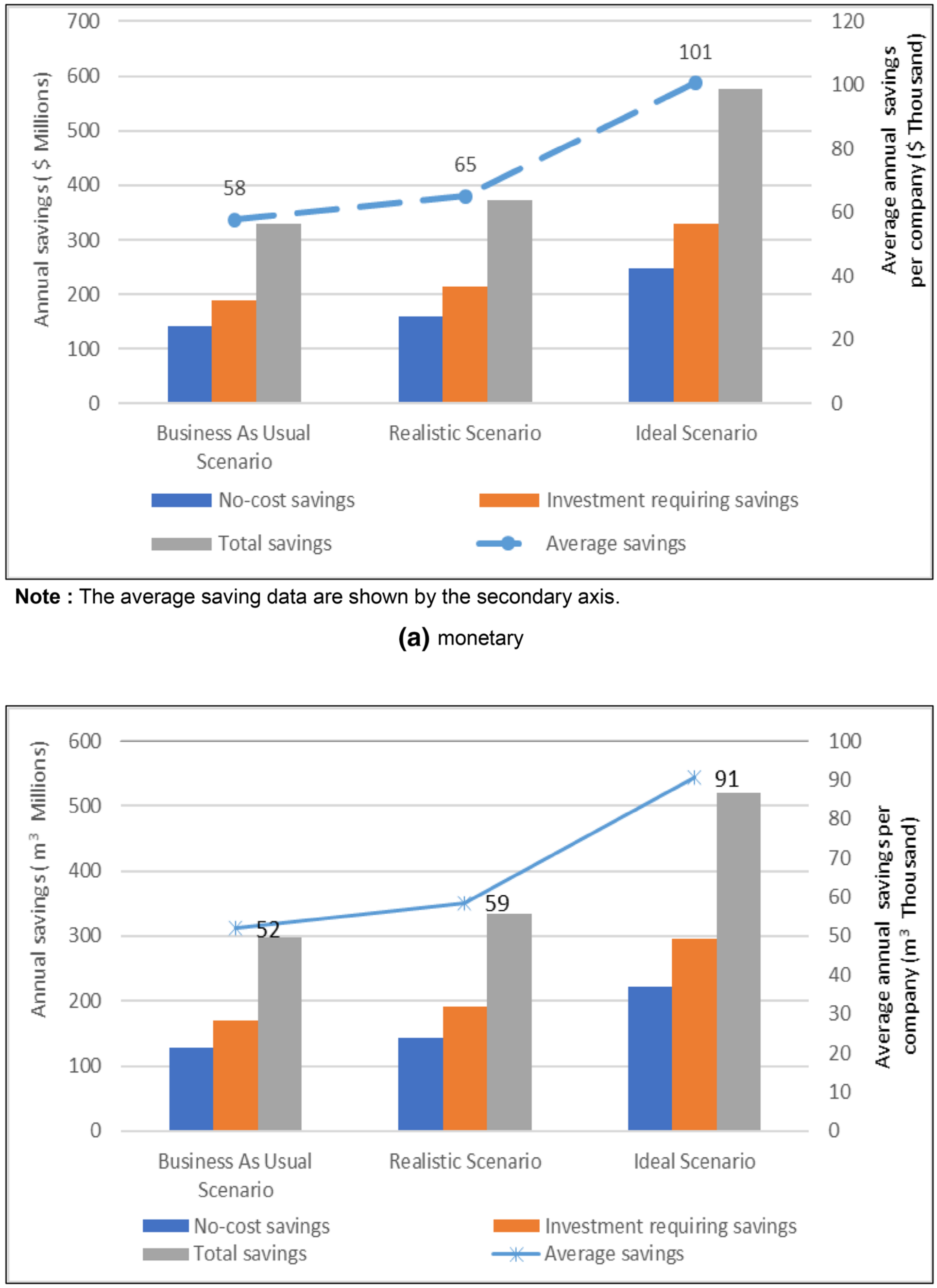
Fig. 7 Energy-saving potential based on business size



According to the scenarios, "Manufacture of other nonmetallic mineral products" and "Manufacture of textiles" sectors account for 26%–28% and 15–19% of the manufacturing industry's total energy-saving potential, respectively. Based on the scale analyses, it is seen that small-, medium-sized, and large-scale enterprises account for 16%, 26%, and 58% of the total energy-saving potential in the manufacturing industry. Once again, TR10 (Istanbul) and TR42 (Kocaeli, Sakarya, Düzce Bolu, Yalova) regions had the highest quantitative energy savings.

In Turkey, primary energy sources mostly consist of fossil fuels, and electricity generation is mainly based on natural gas. Turkey is a net energy importer and has a dependency ratio about 75%. Accordingly, Turkish government has increasingly attached importance for measuring and improving energy efficiency and decreasing energy imports. As a

Fig. 8 Water-saving potential



Note : The average saving data are shown by the secondary axis.

(a) monetary

Note : The average saving data are shown by the secondary axis.

(b) quantitative

result, the Energy Efficiency Law was adopted in 2007 and the Energy Efficiency Strategy Document came into force in 2012. After these regulations, the government aims to improve energy intensity by 20% until 2023 (Özkara and Atak 2015). In this case, Turkey should use its resources effectively and increase energy efficiency in all the sectors including the manufacturing industry and also investments in renewable energy.

Though it is found in the study that there is a significant difference between raw materials and energy inputs when compared in terms of savings to be achieved with improvements that do not require any investments, one of the most

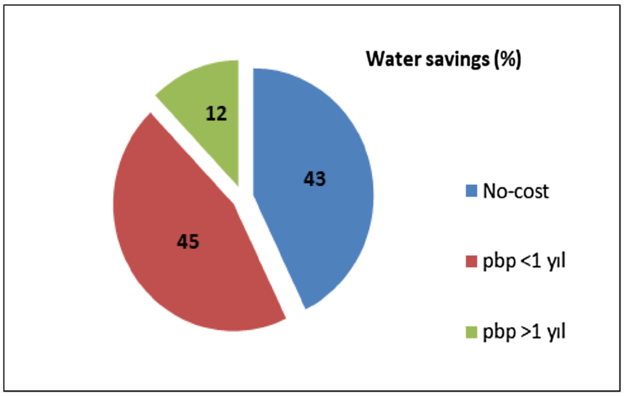


Fig. 9 Distribution of water savings according to investment requirement (realistic scenario-monetary)

important reasons for this may be interpreted as the fact that enterprises have focused their attention on energy efficiency activities in recent years and dedicated a large part of the cleaner production studies that do not require investment. At this point, it is thought that significant progress has been achieved in terms of energy savings through the several projects and support provided. Also, the existence of the Energy Efficiency Law that specifically addresses energy efficiency has laid the groundwork to accelerate activities in this field. Based on these aspects, we can say that there is a need for more improvements that require investment for tapping the available saving potential in the field of energy.

Since there is a strong relationship between sustainable water management and economic development, it is of importance to make some studies evaluating the water-saving potential and to ensure investment in the water sector while taking environmental concerns into account. In our study, total water-saving potential of the selected five sectors constitutes approximately 91% of the manufacturing industry's total water-saving potential. The "Manufacture of basic metals" draws attention among these sectors which accounts for 68–70% of the manufacturing industry's total water-saving potential by itself according to the scenarios. Besides, 12–14% of the manufacturing industry's total water-saving potential is accounted for by "Manufacture of textiles" sector. The medium-sized and large-scale enterprises account for 9–11% and 89–91% of the manufacturing industry's estimated total water-saving potential, respectively. On the other hand, almost all the potential is concentrated in large-scale enterprises in the "Manufacture of basic metals" and "Manufacture of chemicals and chemical products." In other selected sectors, the medium-sized enterprises are expected to account for 25–37% of the total potential. Also, TR63 (Hatay, Kahramanmaraş, Osmaniye) and TR22 (Balıkesir, Çanakkale) regions had the highest quantitative water-saving potential in the Turkish manufacturing industry.

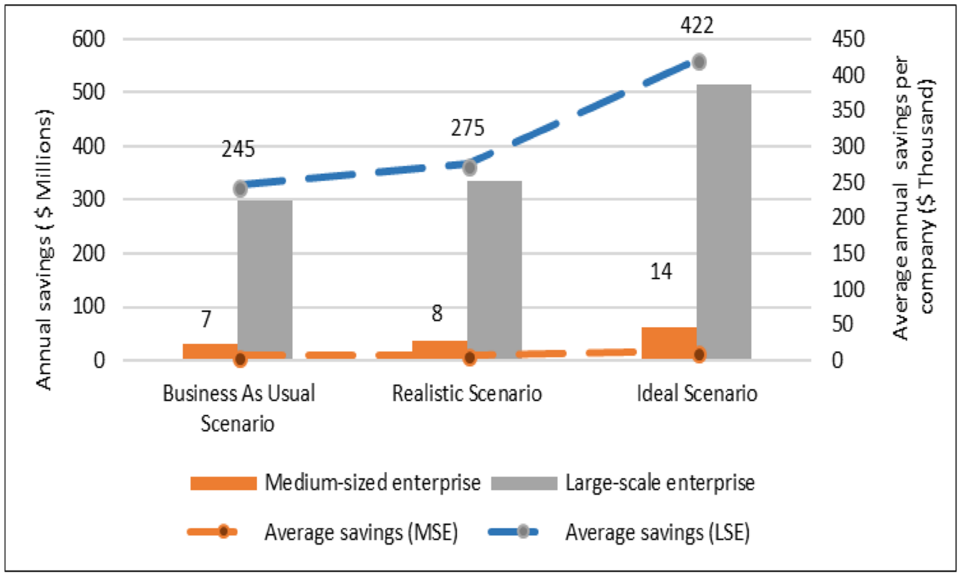
The conclusion from the face-to-face interviews conducted on the water-saving potential and the onsite visits is that water consumption is not monitored adequately in the manufacturing processes and that enterprises do not prefer to take conservation measures because they use water either at a very low price or free of charge. In this context, further policies and measures are needed to encourage more efficient use of water in the manufacturing industry, endorse cleaner production practices for water savings. There should also be efforts to regulate and inspect water consumption in the manufacturing.

As Turkey is a developing country, the water resources should be used in an efficient way while minimizing negative environmental impacts. Industrial water consumption is expected to increase in the near future, so serious measures should be taken in order to conserve water resources from depletion due to industrial activities. In this case, it is important to point out the restructuring policies that are directing the resource efficiency, and giving special emphasis to socioeconomical bodies, laws and legal regulations.

The result of the study shows that 70% of the total saving potential is obtained by no-cost investments and investments with a payback period lower than 1 year. In the UK experience, 60% of the total saving potential is to get the investments with a payback period longer than 1 year (DEFRA 2011). This may be due to the difference in level of development among economies. The UK manufacturing industry may have utilized majority of the short-term savings potential in the past. Another paper also emphasizes the potential energy savings with short payback period investments in Turkey (Karabal 2012). The study estimates an average of $ 127,000 a year in energy savings, which is about 30% more than our ideal scenario. It is necessary to be cautious when comparing these studies, due to methodological differences and assumptions.

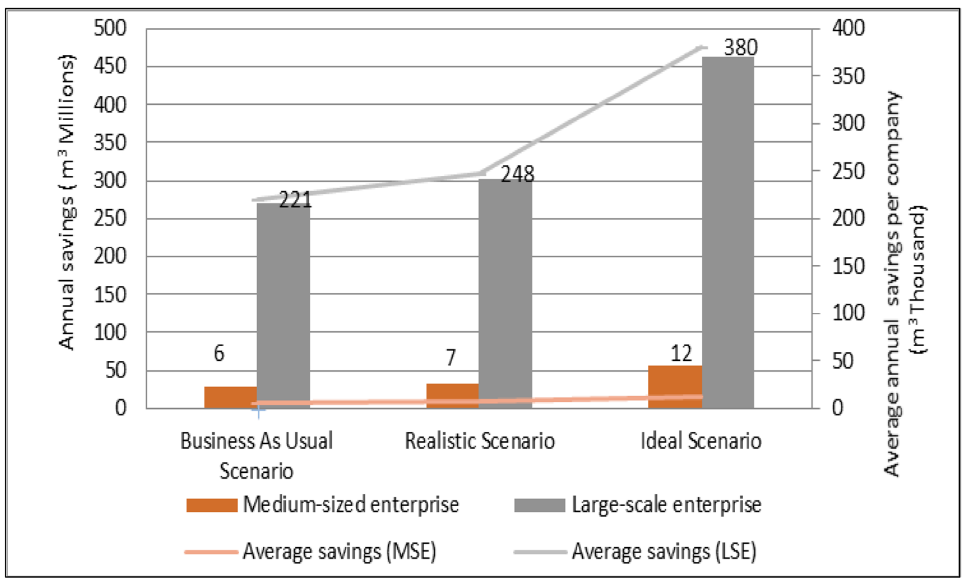
The results of this study may be useful for managers working in public and private sectors. The study may be a roadmap for the savings and incentive policies that public managers will create in the manufacturing sector, as it reveals the magnitude of potential savings for each source.

Fig. 10 Water-saving potential based on business size



Note: The average saving data are shown by the secondary axis.

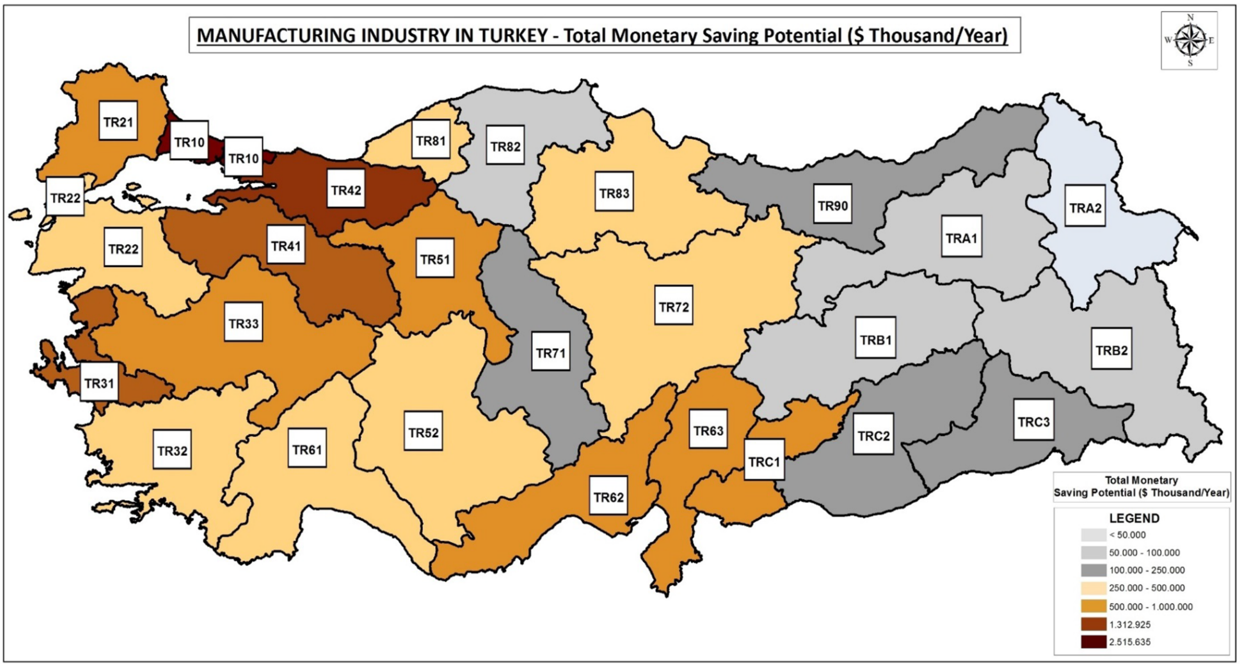
(a) monetary



Note: The average saving data are shown by the secondary axis.

(b) quantitative

As it shows the size of investments required to achieve resource savings, it can help to allocate scarce resources more effectively and identify the priorities. Similarly, firm managers can see which resources have more savings potential in their sectors. Future research may focus on the resource-efficient potential on specific sectors or regions. Therefore, the results will be more accurate and more realistic.



Note: Regions: TR10 İstanbul; TR21 Tekirdağ, Edirne, Kırklareli; TR22 Balıkesir, Çanakkale; TR31 İzmir; TR32 Aydın, Denizli, Muğla; TR33 Manisa, Afyon, Kütahya, Uşak; TR41 Bursa, Eskişehir, Bilecik; TR42 Kocaeli, Sakarya, Düzce, Bolu, Yalova; TR51 Ankara; TR52 Konya, Karaman; TR61 Antalya, Isparta, Burdur; TR62 Adana, Mersin; TR63 Hatay, Kahramanmaraş, Osmaniye; TR71 Kırıkkale, Aksaray, Niğde, Nevşehir, Kırşehir; TR72 Kayseri, Sivas, Yozgat; TR81 Zonguldak, Karabük, Bartın; TR82 Kastamonu, Çankırı, Sinop; TR83 Samsun, Tokat, Çorum, Amasya; TR90 Trabzon, Ordu, Giresun, Rize, Artvin, Gümüşhane; TRA1 Erzurum, Erzincan, Bayburt; TRA2 Ağrı, Kars, Iğdır, Ardahan; TRB1 Malatya, Elazığ, Bingöl, Tunceli; TRB2 Van, Muş, Bitlis, Hakkari; TRC1 Gaziantep, Adıyaman, Kilis; TRC2 Şanlıurfa, Diyarbakır; TRC3 Mardin, Batman, Şırnak, Siirt

Fig. 11 Map of Turkey's saving potential at a regional level within NUTS 26

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