Energy Policy 39 (2011) 7922–7929

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

An application of energy and exergy analysis in agricultural sector of Malaysia

J.U. Ahamed [a], R. Saidur [a,*], H.H. Masjuki [a], S. Mekhilef [b], M.B. Ali [a], M.H. Furqon [a]

[a] Department of Mechanical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Department of Electrical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 9 November 2010
Accepted 23 September 2011
Available online 21 October 2011

Keywords:
Exergy
Agricultural sector
Malaysia

ABSTRACT

Thermodynamic losses usually take place in machineries used for agricultural activities. Therefore, it is important to identify and quantify the losses in order to devise strategies or policies to reduce them. An exergy analysis is a tool that can identify the losses occurred in any sector. In this study, an analysis has been carried out to estimate energy and exergy consumption of the agricultural sector in Malaysia. Energy and exergy efficiencies have been determined for the devices used in the agricultural sector of Malaysia, where petrol, diesel and fuel oil are used to run the machineries. Energy and exergy flow diagrams for the overall efficiencies of Malaysian agricultural sector are presented as well. The average overall energy and exergy efficiencies of this sector were found to be 22% and 20.728%, respectively, within the period from 1991 to 2009. These figures were found to be lower than those of Norway but higher than Turkey.

1. Introduction

Agriculture supplies people with food and other necessities of living. Different machineries such as tractors, trolleys, cultivators, etc. are used for agricultural activities. Petrol, diesel and fuel oil are used as the sources of energy to operate these machineries. It is known that before 1970, energy was abundant and cheap and therefore not a major concern. However, fossil fuels are limited and will be exhausted within 100–150 years. Moreover, emission released by burning fossil fuels is responsible for concerns such as global warming, greenhouse-gas emissions, climate change, etc. Therefore, using resources optimally is a major issue these days. Many researchers have worked on energy savings, management, energy-saving policies and many factors in different sectors, available in the literatures (Saidur et al., 2010; Masjuki et al., 2001; Taufiq et al., 2007; Saidur, 2010; Mahlia et al., 2011). Recently, scientists have been working on the thermodynamic quality aspect of energy for different sectors and countries. The main idea of these works is to identify thermodynamic losses taking place during the operation of different machineries in different sectors. Exergy analysis describes the quality of energy using the conservation of mass and energy principles and the second law of thermodynamics for designing and analysis of energy systems. An exergy analysis can distinguish between high-quality and low-quality energy sources and their uses in various sectors. It also gives an opportunity to match high-quality energy sources with high-temperature applications to acquire higher efficiencies. This cannot be done by energy analysis since an energy analysis merely gives information on the quantity of energy. It does not consider the quality aspect of energy. In this regard, an exergy analysis can be used as a primary tool in addressing the impact of energy resources utilization on the environment and state. It is a suitable technique for furthering the goal of more efficient energy-resource uses, as it can identify the locations, types and true magnitudes of exergy destructions (losses) and wastes (Dincer, 2002a, 2002b; Dincer and Al-Muslim, 2001; Rosen and Dincer, 1999; Saidur et al., 2010; Ahamed et al., 2011).

Many studies have already been carried out on energy and exergy utilizations, which were introduced by Reistad (1975) in the U.S.A. Since then it has been applied for several countries [e.g. Canada, (Terkovics and Rosen, 1988; Lemieux and Rosen, 1989; Rosen, 1992), Japan, Finland and Sweden (Wall, 1990, 1991), Italy (Wall et al., 1994), Turkey (Ozdogan and Arikol, 1995; Rosen and Dincer, 1997; Utlu and Hepbasli, 2004, 2005), China (Xi and Chen, 2005), Malaysia (Saidur et al., 2006, 2007a,b,c; Hasanuzzaman et al., 2011), Iran (Avara and Karami, 2010) and the U.K (Hammond and Stapleton, 2001)]. However, it is found that there are limited studies on energy and exergy utilization in the agricultural sector. For instance, Dincer et al. (2005) carried out an important analysis on energy and exergy for the agricultural sector of Saudi Arabia.

It is expected that this analysis will be useful for ASIAN regions and some other countries. This will also pave the way for further

* Corresponding author. Tel.: +603 79674462; fax: +603 79675317.
E-mail addresses: saidur@um.edu.my, saidur912@yahoo.com (R. Saidur).

0301-4215/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2011.09.045

Nomenclature

m	mass of the fuels (kg/s)
I	exergy destruction (J)
S	entropy (J/°K)
P_0	atmospheric pressure (bar)
T_0	ambient température (°C)
E^W	exergy flow (J/s)
E^Q	exergy Flow for heat energy (J/s)
W	shaft work (W)
H	higher heating value (KJ)
X	no. of year starting from 1991
Y	energy consumed in the year, x

Greek symbols

ε	specific exergy (J/kg)
ψ	exergy efficiency
η	energy efficiency
γ	exergy grade function
f	weighing factor of the fuels

Subscripts

in	input condition
ex	output condition
ff	fuel
m, e	electro-mechanical system
o	overall system
i	number of years

improvement in true efficiency by reducing thermodynamic losses via applying feasible technologies. Policy makers of Malaysia and other countries can compare energy use and exergy efficiencies with other countries and take measures to improve the efficiencies of the machines used in this sector. These comparisons will serve as benchmark with other studies as well.

2. An overview of the agriculture sector in Malaysia

The agriculture sector of Malaysia uses about 1% of the total national energy demand (NEB, 2008). The final energy utilized by different sectors in Malaysia is presented in Fig. 1 for the year 2008. This energy is used in palm, rubber and cocoa plantations to supply food and other end uses for the society. Ideally, fuel used by various agricultural machineries must be set to a certain level in order to ensure that they use energy efficiently.

The agricultural sector contributed to about 8.67% of gross domestic product (GDP) in 2006 and 11.3% of total exports. Approximately, 14.6% of the total population of the country are engaged in agriculture, and operate 6.6 million hectares farm holdings (MOA, 2006).

Agriculture is a fundamental prerequisite for a society's development and improvement of people's life generally for global society and especially for Malaysia. As the Malaysian economy has grown rapidly in recent years, the agricultural sector has been realized

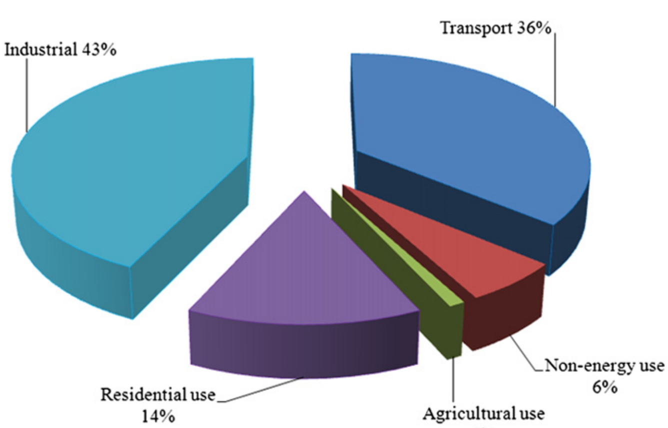


Fig. 1. Final energy usage by different sectors in 2008 (http://epu.gov.my, 26/06/2010).

important for both continuous economic growth and improving the living standards. The agricultural sector will remain strategically important as a provider of food and raw materials for the agro-based and resource-based industrial development during the National Agriculture Policies 3 (NAP3).

With the increasing demand for agricultural products along with the unconstrained expansion of the Malaysia's population, the number of farms has grown year by year in this country. Consequently, fossil fuel use in this sector is increased (UN, 2006).

Malaysia made policies to improve the performance of agricultural sectors. Three policies were emphasized to improve its agriculture sector while conserving energy. The policies are described below:

I. National Agriculture Policies 1 (1984–1991).
- Focused on expansionary policy on exporting crops (i.e. oil palm and cocoa).
- Using abundant land & developing adequate manpower.
- Government investment on infrastructure, institutional building, new land developments for oil palm and cocoa and in-situ development to resolve uneconomic farm size and low productivity among small holders.

II. National Agriculture Policies 2 (1992–1997).
- Greater focus on issues of productivity, efficiency and competitiveness.
- Addressing the linkages with other economic sectors.
- Shifting new area development to in-situ development.

III. National Agriculture Policies 3 (1998–2010).
- To find alternatives to manufacturing sector after the Asian financial crisis in year 1997.
- To establish agro-food sub-sector to be an engine of growth to build up the agriculture sector.
- To further develop agro-food sub-sector as well as agro-based industries.

3. Theoretical and mathematical formulations for exergy analysis

These have been briefly presented in the following sections.

3.1. The useful concept of exergy

The first law of thermodynamics is concerned only with the conservation of energy. It does not provide any information on how, where, and what amount of performance is degraded. An exergy analysis provides increased and deeper perception into the process, as well as new ideas for improvements (Saidur et al., 2007b; Dincer, 2002a). Dincer (2002b) reported the relationship between energy and exergy, exergy and the environment, energy and sustainable development and energy policy making details. Exergy analysis is a powerful tool in designing, optimization and performance evaluation of energy systems. The principles and methodologies of exergy analysis are well-established as reported by (Gagioli, 1998; Bejan, 1988, 1982; Wark, 1995; Moran, 1982). An exergy analysis is usually aimed to determine the maximum performance of the system (Saidur et al., 2010; Dincer et al., 2004a).

Exergy can be defined as a measure of maximum capacity of an energy system to perform useful work as it proceeds to a specified final state in equilibrium within the surroundings. In simple words, we can describe exergy as the ability to produce work. The available work that can be extracted from an energy source depends on the state of the surrounding. The greater the temperature differences between an energy source and its surroundings, the greater the capacity to extract work from the system. Energy and exergy are different parameters (Simpson and Kay, 1989) even though they were equivalent in their values.

In any real process (irreversible), exergy is consumed or destroyed or lost since exergy cannot be conserved. The exergy balance equations can be shown as follows:

$$\text{Exergy input} - \text{Exergy out} - \text{Exergy consumption} = \text{Exergy accumulation} \quad (1)$$

$$\sum_{in} \varepsilon_{in} m_{in} - \sum_{ex} \varepsilon_{ex} m_{ex} + \sum_{r} E^{Q} - E^{W} - I = 0 \quad (2)$$

The amount of exergy destroyed within the system due to irreversibility during a process can be expressed by Eq. (2).

$$I = T_o S_{gen} \quad (3)$$

here the exergy consumption, I can be classified into two categories:

$I > 0$ for an irreversible process;
$I = 0$ for a reversible process.

Since $m_{in} = m_{ex} = 0$, for a closed system, Eq. (2) can be simplified to

$$\sum_{r} E^{Q} - E^{W} - I = 0 \quad (4)$$

3.2. Chemical exergy

For hydrocarbons as fuels, the specific exergy reduces to chemical exergy expressed by Eq. (5). Table 1 shows exergy grade function for different types of fuels.

$$\varepsilon_{ff} = \gamma_{ff} H_{ff} \quad (5)$$

Table 1
Typical values of H_{ff}, ε_{ff} and γ_{ff} for the fuels encountered in the present study (Dincer et al., 2004a; Reistad, 1975; Rosen and Dincer, 1997).

Fuel	H_{ff} (kJ/kg)	Chemical exergy (kJ/kg)	γ_{ff}
Gasoline	47,849	47,394	0.99
Natural Gas	55,448	51,702	0.93
Fuel Oil	47,405	47,101	0.99
Diesel	39,500	42,265	1.07
Kerosene	46,117	45,897	0.99

Usually, the specific chemical exergy, ε_{ff} of a fuel at T_o and P_o is approximately equal to higher heating value H_{ff}.

3.3. Reference environment

Evaluation of exergy is always made with respect to a reference environment. The reference environment is in stable equilibrium, acts as an infinite system, a sink or surface for heat and materials, and experiences only internal reversible processes in which its intensive properties (i.e. temperature T_o, pressure P_o, and chemical potentials μ_{j00} for each of the j components) remains constant. Based on Malaysia's weather conditions, minor modifications are done to the model developed by Gaggioli and Petit (1997), which is recommended by Dincer et al. (2004a). In the present analysis surrounding temperature and pressure are considered as $T_o = 25$ °C and $P_o = 100$ kPa. The chemical composition is taken to be saturated air with water vapor, and the following condensed phases are used at 25 °C and 100 kPa: water (H_2O), gypsum ($CaSO_4$, $2H_2O$) and limestone ($CaCO_3$).

3.4. Energy and exergy efficiencies for principle types of processes

The expressions of energy (η) and exergy (ψ) efficiencies for the principle types of processes can be presented by Eqs. (6) and (7), respectively(Dincer et al., 2004a):

$$\text{Energy efficiency}, \eta = \frac{\text{Energy in products}}{\text{Total energy input}} \quad (6)$$

$$\text{Exergy efficiency}, \psi = \frac{\text{Exergy in products}}{\text{Total exergy input}} \quad (7)$$

Exergy efficiencies can often be written as a function of the corresponding energy efficiencies by assuming the energy grade function γ_{ff} to be 'unity', which is commonly valid for the fuels encountered in the present study (kerosene, gasoline, diesel and natural gas) (Dincer et al., 2004a).

3.5. Mean and overall energy efficiencies calculations

Before evaluating the overall mean exergy efficiencies for the agriculture sector, it has to be noted that the outputs of agriculture devices need to be in the form of kinetic energy (shaft work) and energy uses. The exergy associated with shaft work (W) can be expressed by

$$E^{W} = W \quad (8)$$

Thus, for electric shaft work production, the energy and exergy efficiencies of the devices used in agricultural activities can be expressed by

$$\eta_{m,e} = \frac{W}{W_e} \quad (9)$$

$$\psi_{m,e} = \frac{E^{W}}{E^{W,E}} = \frac{W}{W_e} = \eta_{m,e} \quad (10)$$

Gasoline, diesel and fuel oil are used for the machines used in agricultural activities. First, weighted mean energy efficiencies can be found for each type of fuel by multiplying a weighing factor (f) with energy efficiency (η) for that fuel. A weighing factor is the ratio of energy input of each of the fuels to the total sectoral input energy. This can be expressed by

$$\text{Weighing factor}, f = \frac{\text{Energy input of any fuel}}{\text{Total energy input}} \quad (11)$$

$$\text{Weighted energy efficiency of gasoline}, \eta_{gasoline} = \eta_o \times f_{gasoline} \quad (12)$$

Weighted energy efficiency of diesel, $\eta_{diesel} = \eta_o \times f_{diesel}$ (13)

Weighted energy efficiency of fuel oil, $\eta_{fuel\ oil} = \eta_o \times f_{fuel\ oil}$ (14)

Finally, overall mean energy or weighted mean energy efficiency can be expressed by

$$\eta_0 = \eta_{gasoline} + \eta_{diesel} + \eta_{fuel\ oil} \quad (15)$$

Overall weighted mean energy efficiency and estimated operating energy efficiency are similar. In this case, only fuels of same operating efficiencies are used. But in the case of other countries, electrical energy is used for agricultural purposes.

3.6. Mean and overall exergy efficiencies calculations

For fossil fueled shaft work production in agriculture devices, the exergy efficiency can be shown similar to the energy efficiency as follows:

$$\eta_{m,e} = \frac{W}{m_{ff} H_{ff}} \quad (16)$$

$$\psi_{m,e} = \frac{W}{m_{ff} \gamma_{ff} H_{ff}} \quad (17)$$

$$\psi_{m,e} = \frac{W}{m_{ff} \gamma_{ff} H_{ff}} = \frac{\eta_{m,f}}{\gamma_{ff}} \quad (18)$$

To assess the technical performance of agriculture devices, their exergy efficiency is considered as the quotient of the work output over the exergy input, corresponding to above equations. Then, exergy efficiency for the whole sector is the weighted average of the exergy efficiencies of all devices, with the exergy consumption fraction of each form of fuels as the weighting factor. The energy-efficiency data for three modes under consideration used by Reistad (1975), estimated for the US devices, are also assumed to be representative of the devices used in Malaysia. As devices are not operated at rated load generally, so part load efficiencies of their devices are estimated to be 22% for road or agriculture devices such as tractor, lorry taken from Dincer et al. (2005). Using the weighing factor from the Eq. (11), and data for the year 2006, weighted exergy efficiency of the fuels (gasoline, diesel and fuel oil) using Eq. (18) can be expressed as follows:

$$\Psi_{gasoline} = \frac{\eta_{m,e}}{\gamma_{gasoline}} \times f_{gasoline} = \frac{\eta_{gasoline}}{\gamma_{gasoline}} \quad (19)$$

Weighted energy efficiency of diesel:

$$\psi_{diesel} = \frac{\eta_{m,e}}{\gamma_{diesel}} \times f_{diesel} = \frac{\eta_{diesel}}{\gamma_{diesel}} \quad (20)$$

Weighted energy efficiency of fuel oil:

$$\psi_{fuel\ oil} = \frac{\eta_{m,e}}{\gamma_{fuel\ oil}} \times f_{fuel\ oil} = \frac{\eta_{fuel\ oil}}{\gamma_{fuel\ oil}} \quad (21)$$

Therefore, overall exergy efficiency or weighted mean exergy efficiency can be expressed by

$$\psi_0 = \psi_{gasoline} + \psi_{diesel} + \psi_{fuel\ oil} \quad (22)$$

4. Methodology and data sources

4.1. Data sources

Amount of fuel consumption by different machineries used in the agricultural activities are collected from Malaysian National Energy Balance and presented in Table 2.

Table 2
Energy uses data for the agriculture sector in Malaysia from year 1991 to 2009 (NEB, 2009).

Year	Energy Input (GJ)		
	Petrol	Diesel	Fuel oil
1991	126	4895	293
1992	167	15,648	377
1993	126	1590	377
1994	126	17,615	393
1995	126	17,949	417
1996	126	19,581	440
1997	126	19,414	464
1998	126	12,719	488
1999	293	4142	511
2000	167	4184	535
2001	84	4017	559
2002	84	3891	582
2003	126	3975	606
2004	126	3515	629
2005	126	3682	653
2006	126	9832	669
2007	167	10,251	711
2008	167	10,711	711
2009	167	11,297	753

However, it has to be noted that during 1993–2005 fuel oil used in this sector was not available. Therefore, a prediction technique reported in Mahlia et al., (2002) was used to fill this gap. Eqs. (23) and (24) were used to estimate fuel oil used for the foretold years:

$$y = c_0 + c_1 x \quad (23)$$

Using data from Table 2 and Eq. (23), Eq. (24)was developed to project fuel oil used for the years 1993–2005:

$$y = 23.61x - 46689 \quad (24)$$

Using Eq. (24) energy from fuel oil can be found, which is tabulated in Table 3 for the period of 1993–2005.

4.2. Steps and procedures taken for energy and exergy analysis

Energy and exergy efficiencies were determined using Eqs. (6) and (7) considering grade function as unity. The overall energy efficiency can be easily found by dividing total energy produced by total input energy (Dincer et al., 2004a). Using data given in Table 2, the energy efficiencies of the hydroelectric and thermal power plants are obtained. The overall weighted mean was obtained for the energy and exergy efficiencies for the fossil-fuel processes as well. Weighing factors are the ratio of energy input of each of the fuels (either fossil fuel or electric) to the total input energy of this sector (Dincer et al., 2004a). The device exergy efficiencies are evaluated using data for the years 1991–2009. Energy and exergy efficiencies were then used to calculate the overall energy and exergy efficiencies of this sector.

4.3. Data prediction for fuel usage

Unavailable data for fuel oil usage for the period of 1993–2005 was projected using Eq. (24) and presented in Table 3. However, a tractor rated load was taken from the reference (Dincer et al., 2004a, 2005) as there is no data available for Malaysia.

4.4. Data from literatures

The energy and exergy efficiencies of the agriculture sector for few selected countries are obtained directly from different

Table 3
Energy usages data in agriculture sector of Malaysia (MOA, 2010).

Year	Main fuel types	ktoe	Fuel used (GJ)	%	Energy efficiency (%) Rated load	Estimated operating
1991	Petrol	3	126	2.36	28	22
	Diesel	117	4895	92.13	28	22
	Fuel oil	7	293	5.51	28	22
1992	Petrol	4	167	1.03	28	22
	Diesel	374	15,648	96.64	28	22
	Fuel oil	9	377	2.33	28	22
1993	Petrol	3	126	6.04	28	22
	Diesel	38	1590	76.22	28	22
	Fuel oil	9	370	17.14	28	22
1994	Petrol	3	126	0.69	28	22
	Diesel	421	17,615	97.14	28	22
	Fuel oil	8.85	393	2.17	28	22
1995	Petrol	3	126	0.68	28	22
	Diesel	429	17,949	97.06	28	22
	Fuel oil	9.4	417	2.26	28	22
1996	Petrol	3	126	0.63	28	22
	Diesel	468	19,581	97.19	28	22
	Fuel oil	10	460	2.18	28	22
1997	Petrol	3	126	0.63	28	22
	Diesel	464	19,414	97.05	28	22
	Fuel oil	10.5	464	2.32	28	22
1998	Petrol	3	126	0.95	28	22
	Diesel	304	12,719	95.39	28	22
	Fuel oil	11.7	488	3.66	28	22
1999	Petrol	7	293	5.92	28	22
	Diesel	99	4142	83.74	28	22
	Fuel oil	12.22	511	10.33	28	22
2000	Petrol	4	167	3.42	28	22
	Diesel	100	4184	85.63	28	22
	Fuel oil	12.8	535	10.95	28	22
2001	Petrol	2	84	1.80	28	22
	Diesel	96	4017	86.20	28	22
	Fuel oil	13.4	559	12.00	28	22
2002	Petrol	2	84	1.84	28	22
	Diesel	93	3891	85.32	28	22
	Fuel oil	14	582	12.77	28	22
2003	Petrol	3	126	2.68	28	22
	Diesel	95	3975	84.45	28	22
	Fuel oil	14.5	606	12.87	28	22
2004	Petrol	3	126	2.95	28	22
	Diesel	84	3515	82.32	28	22
	Fuel oil	15	629	14.73	28	22
2005	Petrol	3	126	2.82	28	22
	Diesel	88	3682	82.54	28	22
	Fuel oil	15.6	653	14.64	28	22
2006	Petrol	3	126	1.18	28	22
	Diesel	235	9832	92.52	28	22
	Fuel oil	16	669	6.30	28	22
2007	Petrol	4	167	1.50	28	22
	Diesel	245	10,251	92.11	28	22
	Fuel oil	17	711	6.39	28	22
2008	Petrol	4	167	1.44	28	22
	Diesel	256	10,711	92.42	28	22
	Fuel oil	17	711	6.14	28	22
2009	Petrol	4	167	1.37	28	22
	Diesel	270	11,297	92.47	28	22
	Fuel oil	18	753	6.16	28	22

previous works: Turkey (Ediger and Huvaz, 2006), Saudi Arabia (Dincer et al., 2004a, b) and Norway (Ertesvåg, 2003). Efficiencies are also calculated using steps and procedures explained in Section 4.2. Then a comparison is made between Malaysia and these countries for the year 2000, shown in Fig. 7.

5. Data analysis, results and discussions

5.1. Mean and overall energy efficiencies

Generally, the overall or mean weighted energy efficiency is determined by dividing the total energy produced by the total energy output. In this problem, all the fuels have the same part loads. Using the part load efficiency, weighted mean energy efficiency of every fuel can be found. Based on the data listed in Table 3, the weighted mean energy efficiency for the agriculture sector in the year 2006 is calculated using Eq. (15):

$$\eta_0 = (0.0118 \times 22) + (0.9252 \times 22) + (0.0630 \times 22) = 22\%$$

From Table 3 it is clear that overall energy efficiency of the agricultural sector in Malaysia is similar i.e. 22% for all the years from 1991 to 2009.

Meanwhile, the weighted mean energy efficiency of the sector is calculated using Eqs. (12)–(14):

Gasoline: $\eta_{gasoline} = 0.0118 \times 22 = 0.2596\%$
Diesel: $\eta_{diesel} = 0.9252 \times 22 = 20.3544\%$
Fuel oil: $\eta_{fuel\ oil} = 0.0630 \times 22 = 1.386\%$

Complete results on weighted mean energy efficiency for gasoline, diesel and fuel oil for the years 1991–2009 is presented in Fig. 2.

The overall mean energy efficiency is calculated using Eq. (15):

$$n_0 = \eta_{gasoline} + \eta_{diesel} + \eta_{fuel\ oil} = 0.2596 + 20.3544 + 1.386 = 22\%$$

With the help of data from Table 3 and using Eq. (15) overall mean energy efficiency for the period 1991–2009 is calculated. Using Eqs. (18) and (22) overall exergy efficiency can be calculated.

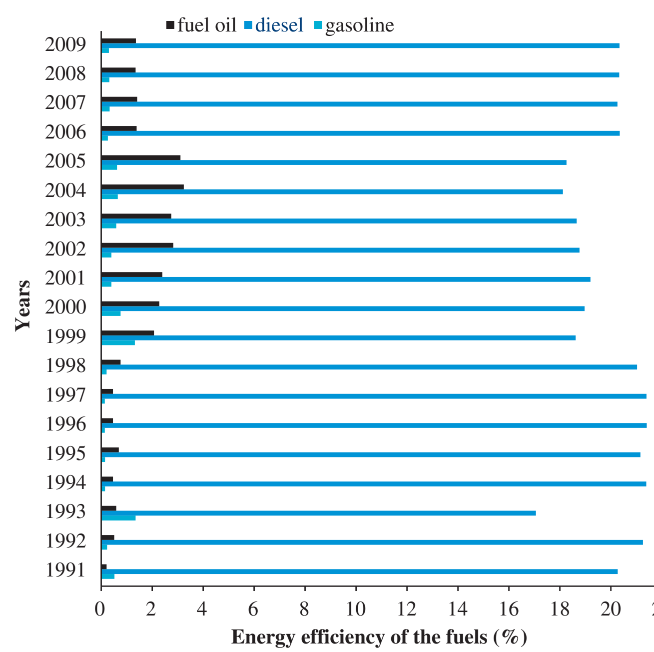


Fig. 2. Weighted mean energy efficiency of the fuels in the agricultural sector of Malaysia for the period 1991–2009.

5.2. Mean and overall exergy efficiencies calculations

Based on the exergy fractions listed in Table 3 and the estimated energy efficiencies, the overall exergy efficiency for agriculture sector in year 2006 is calculated using Eq. (23):

$$\psi_o = 0.2624 + 19.0227 + 1.4000 = 20.685\%$$

Meanwhile, the weighted mean overall exergy efficiency of different types of fuel is calculated using Eqs. (19)–(21):

Petrol:

$$\psi_{gasoline} = 0.0118 \times \frac{22}{0.99} = 0.2622\%$$

or

$$\psi_{gasoline} = \frac{0.259843}{0.99} = 0.2625\%$$

Diesel:

$$\psi_{diesel} = 0.9252 \times \frac{22}{1.07} = 19.0228\%$$

or

$$\psi_{diesel} = \frac{20.354}{1.07} = 19.0224\%$$

Fuel Oil:

$$\psi_{fuel\ oil} = 0.0630 \times \frac{22}{0.99} = 1.4000\%$$

or

$$\psi_{fuel\ oil} = \frac{1.3858}{0.99} = 1.3998\%$$

In this way, weighted mean exergy efficiencies of the fuels between 1991 and 2009 are calculated and complete results for the years 1991–2009 is presented in Fig. 3.

The overall exergy efficiency can be calculated using Eq. (22):

$$\begin{aligned}\Psi_0 &= \psi_{gasoline} + \psi_{diesel} + \psi_{fuel\ oil} \\ &= 0.2625 + 19.0224 + 1.3998 \\ &= 20.6874\%\end{aligned}$$

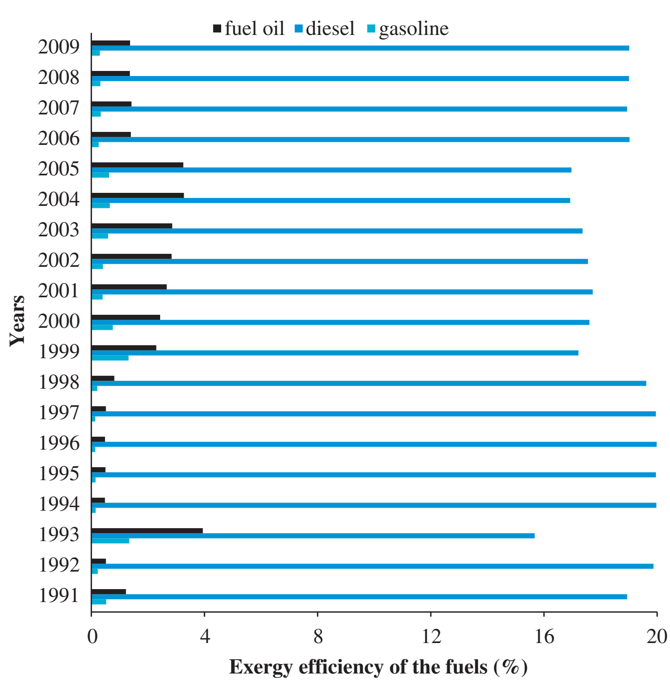


Fig. 3. Weighted mean exergy efficiency of the fuels in the agricultiural sector in Malaysia for the period 1991–2009.

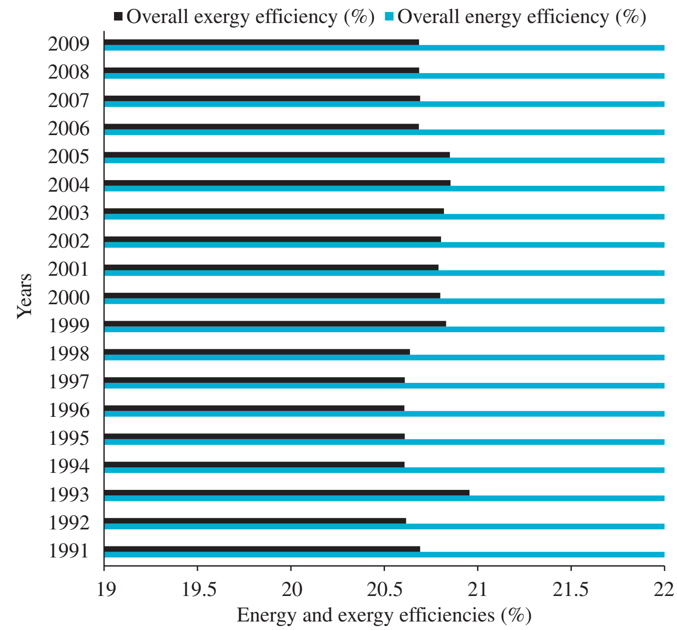


Fig. 4. Overall energy and exergy efficiency for Agriculture Sector in Malaysia for the period 1991–2009.

Table 4
Average energy & exergy efficiency from year 1991 to 2009.

Types of fuel	Average energy efficiency (%)	Average exergy efficiency (%)
Gasoline	0.463	0.467
Diesel	19.784	18.489
Fuel oil	1.753	1.771
Overall average	22.00	20.727

In this way, overall exergy efficiencies for the years 1991–2009 are calculated and presented in Fig. 4.

Maximum exergy efficiency occurred in 1993. The weighing factor and grade function of gasoline and fuel oil are higher compared to those of diesel. Hence the exergy efficiency of diesel was the lowest and that of gasoline and fuel oil are higher in this year. During 1991–2009 (19 years), the average energy and exergy efficiencies of the given fuels can be calculated by dividing the sum of exergy efficiencies of the fuel by nineteen. Average exergy efficiency of gasoline is calculated as follows:

$$\begin{aligned}&= \frac{\sum_{i=1}^{i=19} \psi_i}{n} \\ &= [0.53 + 0.23 + 1.34 + 0.15 + 0.15 + 0.14 + 0.14 + 0.21 \\ &\quad + 1.32 + 0.76 + 0.40 + 0.41 + 0.59 + 0.66 + 0.63 + 0.26 \\ &\quad + 0.33 + 0.32 + 0.30]/19 = 8.878/19 = 0.467\%\end{aligned}$$

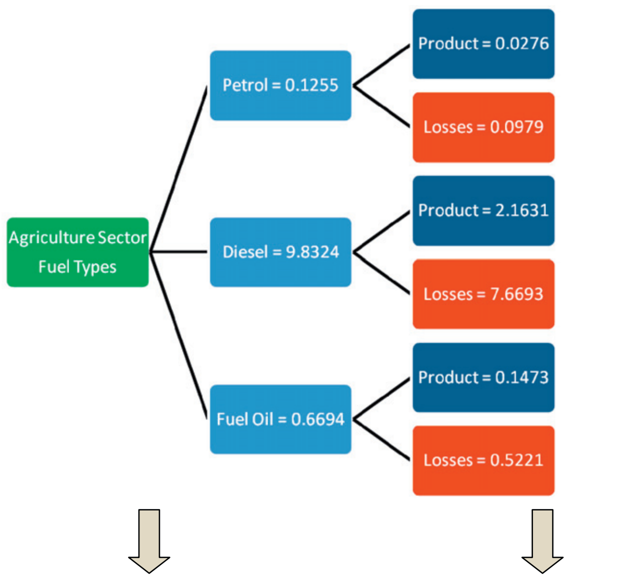
Using the same procedure, average energy and exergy efficiencies of the fuels in this period are calculated and tabulated in Table 4.

From Table 4, it is found that the overall average energy and exergy efficiency in the agricultural sector in Malaysia for the period 1991–2009 are 22% and 20.727%, respectively.

5.3. Discussions

5.3.1. Energy and exergy analysis

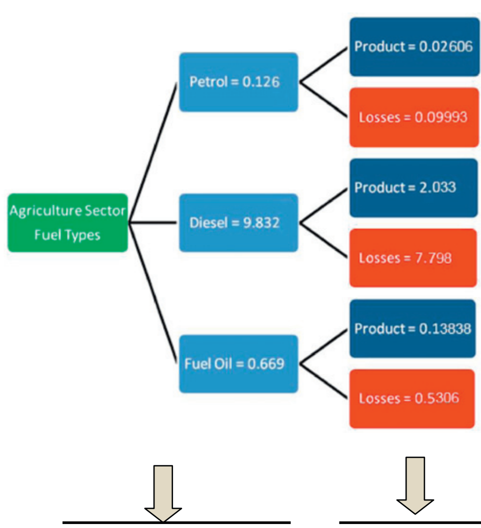
In this section, we combined the overall energy and exergy efficiencies of Agriculture sector in Malaysia. In this regard, the calculation of combined overall energy and exergy efficiencies of different types of fuel is presented in the previous section. Energy use,



Total Energy Inputs = 10.6274 TJ   Total Energy Products = 2.3380 TJ

$$\textit{Overall Energy Efficiency} = \frac{\textit{Total Energy Products}}{\textit{Total Energy Inputs}} = \frac{2.3380}{10.6274} = 22\%$$

Fig. 5. Energy flow diagram of Agriculture Sector in Malaysia for the year 2006. Numerical values are in TJ/year. Losses represent wasted energy emissions.



Total Exergy Inputs = 10.6274 TJ   Total Exergy Products = 2.19819 TJ

$$\textit{Overall Exergy Efficiency} = \frac{\textit{Total Exergy Products}}{\textit{Total Exergy Inputs}} = \frac{2.199819}{10.6274} = 20.685\%$$

Fig. 6. Exergy flow diagram of Agriculture Sector in Malaysia for the year 2006. Numerical values are in TJ/year. Losses represent wasted energy emissions.

the sectorial energy and exergy flow diagrams and economic analysis are constructed for the year 2006 as shown in Figs. 5 and 6. The overall energy and exergy efficiencies of Agriculture sector in Malaysia for the years 1991–2009 are shown in Fig. 7. For illustration, the calculation of overall energy efficiency of all fuel types used in Malaysia's Agriculture sector for the year 2006 is shown as follows:

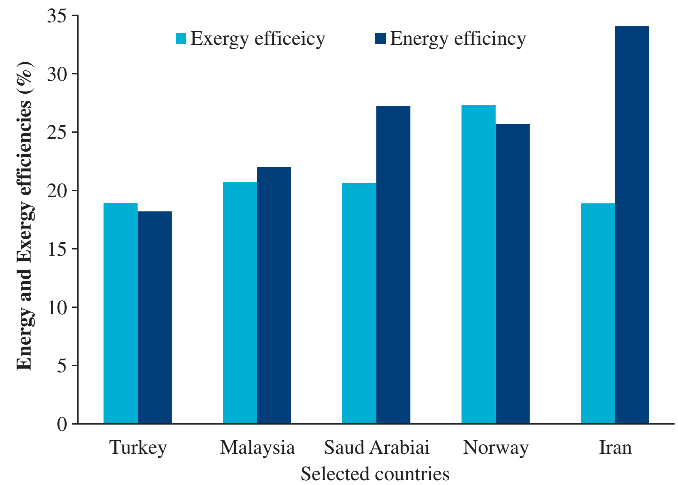


Fig. 7. Comparison of energy and exergy efficiencies of the agriculture sector of Malaysia with other selected countries.

Total energy input	$=254$ ktoe
	$=10{,}627$ GJ
Petrol output	$=\eta_o \times$ total energy input in fuel type-petrol
	$=0.22 \times 126$ GJ
	$=28$ GJ
Diesel output	$=\eta_o \times$ total energy input in fuel type-diesel
	$=0.22 \times 9832$ GJ
	$=2163$ GJ
Fuel oil output	$=\eta_o \times$ total energy input in fuel type-fuel oil
	$=0.22 \times 669$ GJ
	$=147$ GJ

Since the energy grade function of some fuels is assumed to be '1', exergy inputs are equivalent to energy inputs.

Petrol output	$=\psi_o \times$ total energy input in fuel type-petrol
	$=0.20685 \times 126$ GJ
	$=26.06$ GJ
Diesel output	$=\psi_o \times$ total energy input in fuel type-diesel
	$=0.20685 \times 9832$ GJ
	$=2033.75$ GJ
Fuel oil output	$=\psi_o \times$ total energy input in fuel type-fuel oil
	$=0.20685 \times 669$ GJ
	$=138.38$ GJ

The exergy flow diagram shown in this study can be considered as a powerful tool to indicate a true picture of the sector.

5.3.2. Comparison with other countries

In this section, energy and exergy efficiencies of agriculture sector in Malaysia are compared with those of some selected countries. Overall energy and exergy efficiency of the agricultural sector in Malaysia (from Table 4) is compared with Turkey (Ediger and Huvaz, 2006), Saudi Arabia (Dincer et al., 2004a), Norway (Ertesvåg, 2003) and Iran (Avara and Karami, 2010). Comparative results are presented in Fig. 7.

It has been observed that exergy efficiency of Saudi Arabia and Malaysia are higher than Iran. It has been found that pump energy efficiency in Iran is 90% (Avara and Karami, 2010) and Malaysia uses diesel engines with energy efficiency of 22% (Avara and Karami, 2010). On the other hand, pump has less exergy efficiency (4.53%) than diesel engine (22%). It has been noted that Malaysia is the only one using diesel engine. Therefore, exergy efficiency is higher in Malaysia compared to Iran (Saidur et al., 2007b).

Fig. 7 shows that the exergy efficiency of agriculture sector in Malaysia is higher than Turkey and Saudi Arabia in the year 2000. However, it was observed that the agriculture sector in Malaysia is less exergy efficient than Norway.

6. Conclusions

This study has achieved some important findings about energy and exergy analysis of the agricultural sector in Malaysia. The following conclusions can be drawn based on the obtained results:

- The energy and exergy efficiencies for the agricultural sector in Malaysia and the devices used in this sector are accurately determined. The average overall energy and exergy efficiencies of the sector have been found to be 22% and 20.728%, respectively, from 1991 to 2009.
- The highest exergy efficiency is about 20.955% for the year 1993.
- The exergy efficiency of the sector is lower than its corresponding energy efficiency. It is also found that this sector in Malaysia is less efficient than Norway. Exergy efficiency of Saudi Arabia is similar to that of Malaysia.
- Energy and exergy losses have been identified through this analysis. Therefore, a part of these losses can be reduced by applying appropriate technology, management and policy. Government can construct dams and encourage the use of the renewable-energy sources for electric power supply as well.

Acknowledgment

The authors would like to acknowledge the High Impact Research (HIRG) project, University of Malaya, for funding the project. The research has been carried out under the project UM.C/625/1/HIR/022.

References

Avara, A., Karami, M., 2010. Energy and Exergy efficiencies in agricultural and utility sectors of Iran compared with other countries. In: Proceedings of the International Conference on Mechanical and Electrical Technology (ICMET2010), pp. 6–10.
Ahamed, J.U., Saidur, R., Masjuki, H.H., 2011. A review on exergy analysis of vapor compression refrigeration system. Renewable and Sustainable Energy Reviews 15 (3), 1593–1600.
Bejan, A., 1982. Entropy Generation Through Heat and Fluid Flow. Willey, New York.
Bejan, A., 1988. Advanced Engineering Thermodynamics. Wiley, New York.
Dincer, I., 2002a. On energetic, exergetic and environmental aspects of drying systems. International Journal of Energy Research 25 (8), 727–739.
Dincer, I., 2002b. On energetic, exergetic and environmental aspects of drying systems. International Journal of Energy Research 26 (8), 717–727.
Dincer, I., Al-Muslim, H., 2001. Energy and exergy efficiencies of reheat cycle steam power plants. In: Proceedings of ECOS'01, Istanbul, Turkey, July 4–6, pp. 331–338.
Dincer, I., Hussain, M.M., Al-Zaharnah, I., 2004a. Energy and exergy utilization in transportation sector of Saudi Arabia. Applied Thermal Engineering 24, 525–538.
Dincer, I., Hussain, M.M., Al-Zaharnah, I., 2004b. Analysis of sectoral energy and exergy use of Saudi Arabia. International Journal of Energy Research 28, 205–243.
Dincer, I., Hussain, M.M., Al-Zaharnah, I., 2005. Energy and exergy utilization in agricultural sector of Saudi Arabia. Energy Policy 33, 1461–1467.
Ediger, VŞ, Huvaz, Ö, 2006. Examining the sectoral energy use in Turkish economy (1980–2000) with the help of decomposition analysis. Energy Conversion and Management 47 (6), 732–745.
Ertesvåg, I.S., 2003. Energy, exergy, and extended-exergy analysis of the Norwegian society 2000. Energy 30, 649–675.
Gaggioli, R.A., 1998. Available energy and exergy. International Journal of Applied Thermodynamics 1, 1–8.
Gaggioli, R.A., Petit, Pl, 1997. Use the second law first. Chemtech 7, 496–506.
Hammond, G.P, Stapleton, A.J., 2001. Exergy analysis of the United Kingdom energy system. Proceeding of IMechE Part A: Journal of Power and Energy 215 (2), 141–162.
Hasanuzzaman, M., Saidur, R., Rahim, N.A., 2011. Energy, exergy and economic analysis of an annealing furnace. International Journal of Physical Sciences 6 (6), 1257–1266.
Lemieux M.A., Rosen M.A., 1989. Energy and Exergy Analyses of Energy Utilization in Ontario. Research Report, Ryerson Polytechnic University, Toronto.
Mahlia, T.M.I., Masjuki, H.H., Choudry, I.A., 2002. Theory of energy efficiency standards and labels. Energy Conservation and Management 43, 743–761.
Mahlia, T.M.I., Saidur, R., Yanti, P.A.A., Masjuki, H.H., 2011. Role of energy guide labels in consumers purchase decision for household electrical appliances. Energy Education Science and Technology Part A—Energy Science and Research 27 (1), 95–104.
Masjuki, H.H., Saidur, R., Choudhury, I.A., Mahlia, T.M.I., Ghani, A.K., Maleque, M.A., 2001. The applicability of ISO household refrigerator–freezer energy test specifications in Malaysia. Energy 26 (7), 723–737.
MOA, 2006. Overview of Agriculture Sector in Malaysia. Ministry of Agriculture & Agro-Based Industry, 2009, Putrajaya.
MOA, 2010. Overview of Agriculture Sector in Malaysia. Ministry of Agriculture & Agro-Based Industry, 2009, Putrajaya.
Moran, M.J., 1982. Availability Analysis: A Guide to Efficient Energy Use. Prentice-Hall, Englewood Cliffs, NJ.
NEB, 2008. National Energy Balance 1990–2007. Ministry of Energy, Green Technology and Water, Putrajaya, Malaysia.
NEB, 2009. National Energy Balance 1990–2007. Ministry of Energy, Green Technology and Water, Putrajaya, Malaysia.
Ozdogan, O., Arikol, M., 1995. Energy and exergy analyses of selected Turkish Industries. Energy—The International Journal 20, 73–80.
Reistad, G., 1975. Available Energy Conversion and Utilization in the United States.
Rosen, M.A., Dincer, I., 1997. Sectoral energy and exergy modeling of Turkey. ASME—Journal of Energy Resources Technology 119 (3), 200–204.
Rosen, M.A., 1992. Evaluation of energy utilization efficiency in Canada using energy and exergy analyses. Energy—The International Journal 17, 339–350.
Rosen, M.A., Dincer, I., 1999. Exergy analysis of waste emissions. International Journal of Energy Research 23 (13), 1153–1163.
Saidur, R., 2010. A review on electrical motors energy use and energy savings, 2010. Renewable and Sustainable Energy Review 14 (3), 877–898.
Saidur, R., Abdul Khaliq, A.H., Masjuki, H.H., 2006. Analysis of energy and exergy use for process heating in the industrial sector of Malaysia. International Journal of Exergy 3 (2), 119–149.
Saidur, R., Ahamed, J.U., Masjuki, H.H., 2010. Energy, exergy and economic analysis of industrial boilers. Energy Policy 38 (5), 1188–1197.
Saidur, R., Masjuki, H.H., Jamaluddin, M.Y., 2007b. An application of energy and exergy analysis in residential sector of Malaysia. Energy Policy 35 (2), 1050–1063.
Saidur, R., Sattar, M.A., Masjuki, H.H., Abdesselam, H., Shahruan, B.S., 2007c. Energy and exergy analysis in utility and commercial sectors of Malaysia. Energy Policy 35 (3), 1956–1966.
Saidur, R., Sattar, M.A., Masjuki, H.H., Ahmed, S., 2007a. An estimation of the energy and exergy efficiencies for the energy resources use in the transportation sector in Malaysia. Energy Policy 35 (8), 4018–4026.
Simpson, M. , Kay, J., 1989. Availability, Exergy and The 2nd Law.
Taufiq, B.N., Masjuki, H.H., Mahlia, T.M.I., Saidur, R., Faizul, M.S., Mohamad, E.N., 2007. Second law analysis for optimal thermal design of radial fin geometry by convection. Applied Thermal Engineering 27 (8–9), 1363–1370.
Terkovics P.I., Rosen, M.A. 1988. Energy and Exergy Analysis of Canadian Energy Utilization, Research Report, Ryerson Polytechnic University, Toronto.
UN, 2006. Our Planet: Agriculture and Economic Development. United Nations Environment Programme (UNEP), Nairobi, Kenya.
Utlu, Z., Hepbasli, A., 2004. Turkeys sectoral energy and exergy analysis between 1999 and 2000. International Journal of Energy Research 28 (13), 1177–1196.
Utlu, Z., Hepbasli, A., 2005. Analysis of energy and exergy use in Turkish residential—commercial sector. Bulilding and Environment 40, 641–655.
Wall, G., 1990. Energy conversion in the Japanese society. Energy 15 (5), 435–444.
Wall, G., 1991. Exergy Conversions in the Finnish, Japanese and Swedish societies. OPUSCULA Exergy Papers. University College of Eskilstuna/Vasteras, Sweden, pp. 1–11.
Wall, G., Sciubba, E., Naso, V., 1994. Exergy use in the Italian society. Energy—The International Journal 19, 1267–1274.
Wark, K.J., 1995. Advanced Thermodynamics for Engineers. McGraw-Hill, New York.
Xi, J., Chen, G.Q., 2005. Exergy analysis ofenergy utilization in the transportaton sector in China. Energy Policy 34 (14), 1709–1719.