

Al-Tamimi, Abdulrahman; Al-Ghamdi, Sami G.

## Article

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# Multiscale integrated analysis of societal and ecosystem metabolism of Qatar

Abdulrahman Al-Tamimi, Sami G. Al-Ghamdi\*

*Division of Sustainable Development, College of Science and Engineering, Hamad Bin Khalifa University, Qatar Foundation, Doha, Qatar*

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## Abstract

Energy consumption per capita in Qatar reached 17,418 kg of oil equivalent in 2014 which make Qatar one of the biggest energy consumers around the world. Therefore, the Multiscale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) approach has been employed to analyze energy metabolic pattern of socio-economic dimensions of Qatar for the period between 2006 and 2015. The results investigate the relationship between GDP, economic activities, energy consumption, and human time, to determine energy intensity, exosomatic metabolic rate, and economic labor productivity. The major findings show that energy consumption grew at a faster rate than GDP within the same period, and energy consumption per capita and energy intensity grew approximately at the same rate. Besides, the low rate of labor productivity in construction sector drags down the economic labor productivity for the entire economy, especially with the large number of labor in construction sector. Moreover, the correlation between exosomatic metabolic rate and economic labor productivity in the manufacturing sector is unbalanced, whereas the high rates of energy consumption per hour do not depict the low rates of economic labor productivity. Relevant policy decisions can then be formulated and implemented based on the recommendations of this study to help policy makers in the implementation of Qatar National Vision 2030.

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**Keywords:** Energy metabolism; MuSIASEM; Energy intensity; Exosomatic metabolic rate; Economic labor productivity

## 1. Introduction

The entire global energy consumption will rise by 28 percent from the 2015 level of 575 quadrillion to 736 quadrillion Btu in 2040 due to projected robust and long-term economic growth that would fuel the growing demand for energy consumption. One of the critical determinants of growing energy demand in an economy is the Gross Domestic Product (GDP) index that indicates to policy makers the achieved or projected economic growth of a nation. In the period of 2015–2040, the world will record a 3% annual growth from 2015 through to 2040 [1]. Qatar consumed an estimated 17,418 kg of oil equivalent in 2014, while the United States consumed 6793 kg of oil equivalent making Qatar among the largest energy consumers in per capita consumption across the world [2].

\* Corresponding author.

E-mail address: [salghamdi@hbku.edu.qa](mailto:salghamdi@hbku.edu.qa) (S.G. Al-Ghamdi).

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### 1.1. Link between economic growth and energy consumption

Scholars have noted a revival in interest on the association between economic development and energy consumption for these reasons: (a) emerging economies have sustained a growing need for oil consumption to fuel their accelerating economic growth and, (b) the peak oil hypothesis has recently emerged [3]. Despite the popularity of the topic of economic development and energy demand in an economy, academia has not reached a consensus on the permanent and the transitional relationship between the two variables [4]. Thus, the current thinking is that each variable can explain for causality. For instance, where causality emerges from consumption of energy in an economy leading to increased incomes, such a relationship would demonstrate that a nation is an energy-dependent economy. In such an economy, energy shortages can have a disproportionate impact on incomes. Conversely, causality arises from income that spurs higher energy consumption, it denotes that the economy is less energy-dependent. In such an economy, policy makers can enact energy conservation policies without adversely affecting incomes, Jumbo employed electricity consumption, accepting it as a narrow definition of energy definition, to denote energy consumption for those economies that are considerably reliant on electricity as a power source [5]. Until present, research has offered mixed conclusions on the causal relationship between energy utilization in an economy and economic growth. Kraft and Kraft [6] wrote the groundbreaking academic paper on the subject using steps showing bivariate causality. Casualty evidence inferenced was Gross National product, an indicator of economic growth, to impact on energy consumption in the American economy.

### 1.2. Motivation and purpose

This study serves to establish the link between energy consumption and GDP growth in Qatar by analyzing the economic productivity and energy consumption in the country's economic sectors. The analysis adopts an environmental, economic, and social perspective. The paper's methodology of choice is the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM), which allows the investigation of a detailed energy metabolic pattern in hierarchal levels across the entire society. Cognizance on the productivity of each human activity for the whole society in greater resolution will enable decision makers in Qatar to support them in preparing and organizing appropriate energy and sustainability policies and plans.

## 2. Methodology and procedures

### 2.1. Overview of MuSIASEM

MuSIASEM has been used as a method to analyze socio-ecosystems and to simulate possible patterns of energy metabolism, economic productivity and development of societies. This study employs Giampietro and Mayumi's MuSIASEM [7–9], which is a transdisciplinary approach integrating quantitative data from nonequivalent descriptive domains that span across numerous scales and dimensions [10]. The study also employs the “metabolism of human society” concept in characterizing the society's energy processes and material transformations, which are necessary for the society's continued existence [11].

### 2.2. Study area

The nation of Qatar covers an estimated area of 11,607 km<sup>2</sup> extending from halfway along the Arabian Gulf's western coast and northwards. As a Peninsula, Saudi Arabia's is the country only land border and the border stretches to an estimated 86 km<sup>2</sup>. The country's population has grown from an estimated 900,000 in 2005 to an estimated 2.5 million people by August 2017. Factors accounting for the rapid population growth include economic growth, dramatic ballooning of the GDP from the 2005 level of an estimated \$45 billion USD to \$152 billion USD in 2016. Qatar's economic performance depends on its natural resources of petroleum and natural gas, which account for more than 70 percent of the entire revenue of its government. Qatar holds the third largest global reserves of natural gas reserve and is the second-largest global exporter of natural gas [12].

### 2.3. Analytical framework

Relating to MuSIASEM, the implication requires the division of Qatar into the paid-work (PW) sector, and residential sector (RES), both sectors engage in energy consumption for self-maintenance and self-development. The paid-work sector which is responsible for added value in the society can be divided into subsectors that correspond with economic sectors. For instance, oil and gas extraction (EX), manufacturing (MU), construction (CO) the service economic (SE) subsectors. Under such a division of the paid-work sector, such economic activities as agriculture, fishing, and forestry form part of the service sector because of their minimal effect on the nation's energy consumption and Gross domestic product. The whole economy of Qatar is level  $n$  while level  $n-1$  represents those divisions between economic and residential sectors. level  $n-2$  is the sectoral productive levels. The three levels of economic activity do not express a top-down economic hierarchy because they co-evolve with each other, adopting different rhythms. The results are only shown for  $n$  and  $n-2$  due to limitations of text limits.

**Table 1.** Variables used in MuSIASEM.

Acronym	Variable	Description
GDP-flow	GDP	Added value generated by an economy in one year, measured in US dollar (\$).
THA-fund	Total human activity	Total human time a society has available for conducting different activities, measured in hours (h). It is calculating by multiplying: Population * 365 * 24
TET-flow	Total energy throughout	Total primary energy used in an economy in one year, measured in Joules (J). When applied to a sector or sub-sector, we call it $ET_i$ , $HA_i$ , and $GDP_i$

Utilizing MuSIASEM, three variables are used (Table 1): primary energy consumption (a flow), human time given to diverse activities (a fund) and added value generated (a flow). The variables are effective for the whole Qatar (Level  $n$ ) or the level of subsector (level  $n-2$ ). For instance, this study utilizes Qatar's total energy throughput (TET) accounting for total consumption of primary energy. Additionally, the study also adopts primary energy that the paid-work sector (ETPW), the residential sector (ETRES) or the various other subsectors (ETEX, ETMU, ETCO and ETSE) uses. The data used to generate various indicators used in benchmarks comparison including the GDP per hour flow/fund ratios, exosomatic metabolic rate and the economic productivity of labor (ELP) (indicated at Table 2). Energy intensities for either individual sectors, subsectors, or the entire Qatar through division of GDP hour by EMR at the level  $n$ , and by dividing homogeneous assessments of the ratios flows/funds at level  $n-1$ , e.g. by dividing ELPI by EMRI. Importantly, the first series of indicators including EI, EMR, and ELP point to a specific ratio, the flow/fund ratio. Such indicators are valid as benchmarks because of their external referent that provides an anticipated metabolic system typology. In analyzing benchmarks, increased EMRI values reflect increased capitalization levels of a particular sector.

**Table 2.** Metrics used in MuSIASEM.

Indicator	Definition	Unit	Calculation	Measurement
EMR	Exosomatic metabolic rate	MJ/h	TET/ THA	Energy consumption per hour of human time available
ELP	Economic labor productivity	\$/h	GDP/ HA	Added value per hour of human time
EI	Energy intensity for the whole economy	MJ/\$	TET/ GDP	Energy consumption per unit of added value (GDP)

This study utilized energy data from US Energy Information Administration for the period 2006–2015 [13]. In reference to demographic data, the research uses national statistics provided by the Ministry of Statistics and Development Planning of Qatar [14], for both total population and labor statistics such as active population and employment. The research employs the values in determining the number of hours worked in every economic sector.

## 3. Results

### 3.1. Level $n$

Fig. 1 (left) indicates the change in GDP against the change in the primer energy consumption. Generally, energy consumption has seen a steady increase from 410 PJ in 2006 until it exceeded 2000 PJ in 2015. However, there seems to have been years especially in 2012 where the consumption displayed a rapid increase by 31%. The GDP, witness

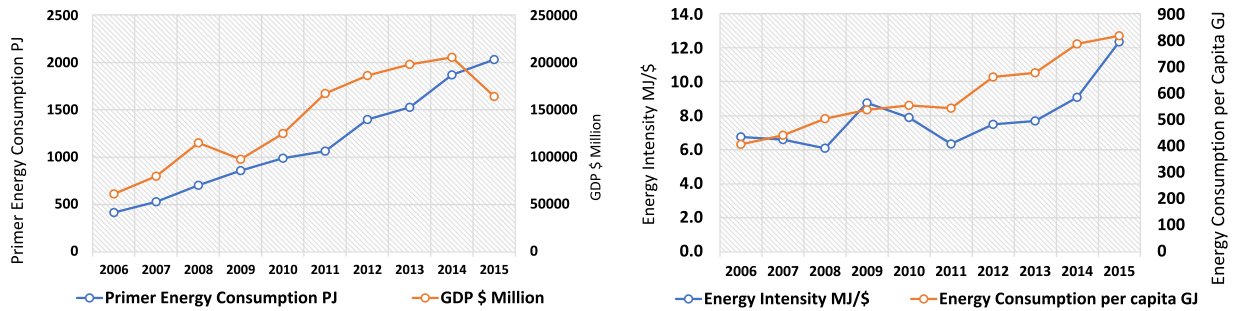


Fig. 1. Primer energy consumption and GDP (left) and energy intensity and energy consumption per capita (right).

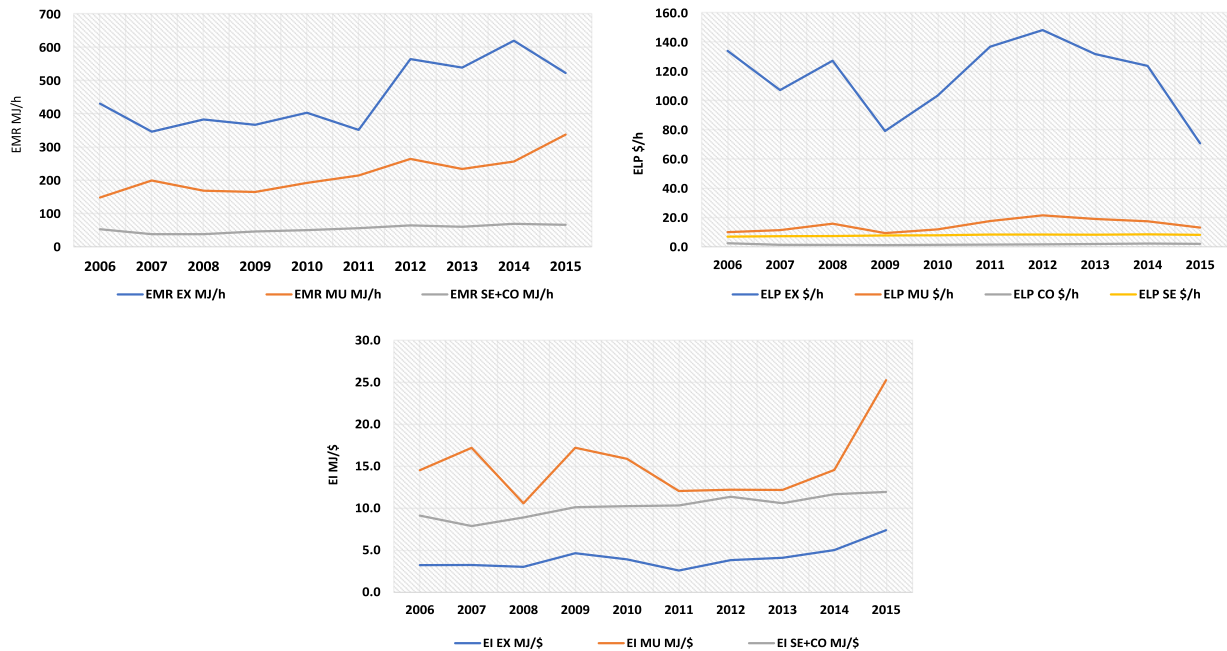
of an increase from 60 billion US\$ in 2006 up to almost 115 billion US\$ in 2008. From 2010, the GDP displayed a gradual increase until it is exceeded 200 billion US\$ in 2014. Finally, the GDP decreased after 2014 because of the drop in oil price as we approached 160 billion US\$ in 2015. It can be concluded that energy consumption has been increasing gradually over the years as human beings demand more energy.

EI in Qatar displays a steady decrease from the year 2006 to the year 2008 at about 6 MJ/\$ as illustrated in Fig. 1 (right). The energy intensity then increases in 2009 to about 8.0 MJ/\$. From 2009, the energy intensity witnesses a decrease in the year 2011. From 2011, the energy intensity displays only a steady increase until the year 2014, from which we observe an exponential increase to 12 MJ/\$ in 2015, for the first time in this ten-year period. The energy consumption per capita increases from 406 GJ in 2006 to 537 GJ in 2009, where it stabilizes to about 2011. In 2011, there is a small decline, and the consumption increases one again to 2012. From 2012, the consumption remains constant, before increases again to about 800 GJ in the year 2015. In general, the behavior of this consumption seems to be alternating quite regularly. However, the general tendency is towards an increase in energy consumption over the ten-year period.

### 3.2. Level $n-2$

From Fig. 2 (top left),  $EMR_{EX}$  displays a decrease from about 430 MJ/h in 2006 to about 350 MJ/h in 2007. From the year 2007 onwards up to around the year 2011, The  $EMR_{EX}$  displays alternating periods of increase and decrease in its value. In 2012, the study observes a steep increase in  $EMR_{EX}$  until it exceeds 560 MJ/h, which is then followed by another period of alternating increases and decreases that stay so until the year 2015.  $EMR_{MU}$  displays an increase from 150 MJ/h in 2006 to 200 MJ/h in 2007. Following this is a gradual decrease to the year 2009, from which the study observes another gradual increase up to touches 260 MJ/h in 2012. From the year 2012, we observe alternating increases and decreases until the year 2015.  $EMR_{SE+CO}$  displays a very slight decrease from 54 MJ/h in 2006 to about 40 MJ/h in the year 2007. Form 2007 onwards, this variable remains constant up to the year 2015. Although there seems to be some very slight increases and decreases between the periods of 2007 to 2015, these changes are so small that they can be neglected. It can generally be said that this variable did not show any significant changes within this period.

$ELP_{EX}$  displays alternating periods of both increases and decreases between the year 2006 and the year 2008 as illustrated in Fig. 2 (top right). In 2009, there is a further drop in  $ELP_{PW}$  due to the financial crisis, it reaches about 9 \$/h, it reaches about 80 \$/h. From the year 2010 onwards, there is observed some significant increase in the values of this variable up to the year 2012. When it was about 150 \$/h. From 2013, onwards, there is some decrease which is followed by a drop in 2015 because oil crises, it was about 70 \$/h.  $ELP_{MU}$  displays alternating periods of increase and decrease from about 10 \$/h in 2006 to about 20 \$/h in 2012. Followed by a gradual but small decline up to 13 \$/h in 2015. The values of  $ELP_{SE}$  are fairly the same throughout this ten-year period. Even though some changes are observable, these changes are so small they can be assumed to be nonexistent, it was about 8 \$/h for the whole period.  $ELP_{CO}$  is unlike the rest of the other variables, this variable remains at throughout the ten-year period around 2 \$/h as represented on the graph, it at no one time displays any changes with respect to time. As displayed in Fig. 2 (bottom).  $EIMU$  displays fluctuating values in the period. In 2007,  $EIMU$  is high at 17 MJ/\$ but drops to about 10 MJ/\$ in 2008, followed by alternating periods of increase and decrease until 2014. In 2015,



**Fig. 2.** Exosomatic metabolic rate for economic activities (top left), economic labor productivity for economic activities (right) and energy intensity rate for economic activities (bottom).

it sharply increases to 25.3 MJ/h. EISE+CO displays a decreasing from about 9 MJ/\$ in 2006 to around 8 MJ/\$ in 2007, followed by period of slightly increasing until it reaches about 12 MJ/h in 2015. EIEX displays alternating periods of slightly increase and decrease from about 3 MJ/\$ in 2006 to about 4 MJ/\$ in 2013. Then, EIEX increases to reach 7.4 MJ/\$ in 2015.

#### 4. Discussion

From economic perspective, the active population grew at a faster rate than the total population as illustrated in Table 3. This has led to attraction of foreign investors who are attracted by different economic activities. The fact that the working population increased rapidly and that much of the increase in tertiary and construction sectors, resulted in a reduction of the economic labor productivity in the period, and this meant unstable jobs in the tertiary and construction sectors. Simply put, the high rates of  $EMR_{EX}$  over the past ten years did not reflect itself on  $ELP_{PW}$ , and that reference to the huge labor of tertiary and construction sectors. In 2015,  $ELP_{PW}$  was 9.6 \$/h, and  $ELP_{EX}$  was 71 \$/h, because of a large pool of labor for the tertiary and construction sector which plays a significant role in weighing down  $ELP_{PW}$ . For example,  $ELP_{SE}$  did not exceed 8.4 \$/h, even though tertiary sector contributed 42% of GDP in 2015. On the contrary, the extraction industry contributes 38% of GDP with  $ELP_{EX}$  71 \$/h. This

**Table 3.** Annual increase, primer energy, GDP, energy intensity, energy per capita.

Year	Primer energy consumption	Gross domestic product (GDP)	Energy intensity	Energy consumption per capita
2010	15.3%	28%	−10.2%	3.2%
2011	7.6%	34.1%	−20.3%	−1.8%
2012	31.7%	11.4%	19%	21.7%
2013	9.2%	6.3%	2.7%	2.4%
2014	22.1%	3.8%	18.2%	16.2%
2015	8.7%	−20.2%	36.3%	4%
Average	19.8%	13.8%	8.8%	8.3%



is because the proportion of labor in tertiary sector is 42% of the total active population. Another example in this regard,  $ELP_{CO}$  was 2.3 \$/h while the contribution for construction sector in GDP was 10%.

Even though most of the energy intensity increases took place in the manufacturing sector. It provides evidence that the manufacturing industry has little socio-economic metabolism value. Also, the fact that manufacturing sector is dependent on oil and gas extraction sector, points to how the economic performance of the Qatar economy affected the sector. So, when  $ELP_{EX}$  had decreased by 43% in 2015,  $ELP_{MU}$  also decreased by nearly half the margin. A comparative analysis energy metabolism between ten countries in 2007 was conducted using the MuSIASEM. Table 4 provides the factors for each of level n and level n-1. The values of Qatar as a country will be compared to other nine countries including Belgium, Denmark, Finland, Netherlands, Slovakia, Czech Republic, Portugal, Estonia, and Slovenia [15].

**Table 4.** Energy metabolism indicators of 10 countries in 2007.

	EI (MJ/\$)	TET (PJ)	GDP (billion \$)	$ET_{PW}$ (PJ)	$ET_{RES}$ (PJ)	$EMR_{PW}$ (MJ/h)	$ELP_{PW}$ (\$/h)
Belgium	12	4271	356	3797	473	600	56
Denmark	11	2083	189	1816	267	404	42
Finland	15	2631	177	2322	309	547	42
Netherlands	13	7722	616	7060	650	591	52
Estonia	13	351	26	294	57	231	21
Slovakia	12	1222	104	1104	118	284	27
Slovenia	7	370	53	291	79	167	31
Czech	11	2765	246	2397	368	236	24
Portugal	8	1827	234	1579	243	165	24
Qatar	7	524	79	504	21	69	11

Qatar has a lower level of GDP at \$ 79 billion, a relatively lower TET of 524 PJ and lowest EI of 7 MJ/\$ compared to the listed countries. However, Qatar has a higher level of GDP at \$ 79 billion. This means that Qatar on the level n scale of the entire society only fair well on GDP, TET, and EI against Estonia and Slovenia among the nine countries. Furthermore, Qatar has a higher  $ET_{PW}$  of 504 PJ and a lower  $ET_{RES}$  of 21 PJ. This again shows that Qatar at level n-1 has a lower energy throughput of the paid sector as well as  $ET_{RES}$  compared to other countries. Qatar however, has a comparatively higher  $ET_{PW}$  and  $ET_{RES}$  compared to two countries of Slovenia and Estonia. Qatar is ranked eighth in energy throughput of PW in the economic sector after Belgium, Denmark, Finland, Netherlands, Slovakia, Czech, and Portugal. Conversely, Qatar has the lowest  $EMR_{PW}$  of 69 MJ/h and  $ELP_{PW}$  of 11 \$/h compared to others. Although the ten countries have not shown much deviation in their  $EMR_{PW}$  and  $ELP_{PW}$ , the exosomatic metabolic rate consumed in the paid sector  $EMR_{PW}$  scores shows that Qatar's score trails behind those of the nine countries. However, it follows Portugal and Slovenia closely at 165 MJ/h and 167 MJ/h respectively while it shows a wider range when compared to Belgium and Finland whose  $EMR_{PW}$  scores are 600 MJ/h and 547 MJ/h in that order. This means that Qatar consumes less exosomatic metabolic energy per hour in the paid sector compared to all other nine countries. From above, Qatar has the third lowest GDP, third lowest TET, and the lowest EI as compared to all the other countries. The economic labor productivity measured as  $ELP_{PW}$  did not shows such disparities. Qatar with an  $ELP_{PW}$  score of 11 \$/h closely follows Estonia's  $ELP_{PW}$  at 21 \$/h and then Portugal at 24 \$/h. Thus, energy labor productivity is lower compared to countries such as Portugal and Estonia. This is attributed to the large pool of labor compared to the nine countries where Qatar is still developing its paid sector.

## 5. Conclusion

The study adopts energy metabolism to identify metabolic patterns and develop appropriate development policies for Qatar which is unique due to its rapid population and urban development. In order to try and achieve this, this paper employs the MuSIASEM model in studying the energy metabolism in Qatar for the period between 2006 and 2015. Human time was investigated as the fund in energy metabolism and to establish a dual-fund to provide an analytical framework. The findings show that Qatar's economic development underwent rapid development characterized by increases in working hours, GDP, and increased energy consumption. Energy consumption grew faster than GDP within the period, and approximate increasing rates for energy consumption per capita and energy intensity. Also, very low rate of labor productivity in construction sector dragged down the economic labor productivity for the whole economy, especially with the large labor pool in construction sector.

The EMR and ELP relationship in the manufacturing sector is unbalanced, while the high rates of EMR do not show the low rates of labor productivity. Structural changes and efforts should be made in the labor structure of construction sector, and energy saving in manufacturing sector. It was proposed to develop an indicator which combines three variables ranging from energy, GDP, to human time in garner more effective methods of studying energy metabolism among the human population. Qatar needs to hasten efforts to enhance labor productivity, strengthen the manufacturing sector and invest in infrastructure. Policymakers need to foster innovation and use of technology for effective competition in global markets. The manufacturing sector consumed 21% of total energy consumption in all economic activities in 2015, while it is responsible for about 10% of total GDP in the same year. Therefore, it is important to encourage the use of renewable energy instead of fossil fuels and this can also be significant in encouraging research, health, education and culture. A combination of energy efficiency and conservation measures are needed to stabilize energy consumption and socio-economic stability. Formulation of policy recommendations aimed at addressing improving the skills of labor instead of just quantity. The labor force has lower energy demands and more productivity, especially in construction sector which it responsible for 10% of GDP. Therefore, priority must be given to skilled-labor and extensive use of technology to replace the large pool of unskilled-labor.

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