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# Energy Consumption in Onion and Potato Production within the Province of El Hajeb (Morocco): Towards Energy Use Efficiency in Commercialized Vegetable Production

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**Abstract**

Energy use efficiency is a key requirement for sustainability in agricultural production, but often overlooked. The aim of this study was to quantify the amount and efficiency of energy consumed in the production of onions and potatoes in El Hajeb province of Morocco. These estimates are of significant importance in informing contemporary policy discourse related to energy subsidy reform in Morocco, and more specifically within an ongoing national strategy for 'modernizing' the agricultural sector under the 'Green Morocco Plan'. Data were collected through the administration of a direct questionnaire with 60 farmers and analyzed using PLANETE. Our results indicate that total energy consumption in onion production is 107483 MJ $ha^{-1}$ with butane (79.5%) as the main source of direct energy. Chemical fertilizers (61.53%) and water for irrigation (30%) were main sources of indirect energy. Energy indices related to energy efficiency ratios, energy profitability and energy productivity were estimated at 0.78, -0.22 and 0.54 kg $MJ^{-1}$, respectively. Total energy consumption in potato production was estimated at 74,270 MJ $ha^{-1}$, with direct energy consumption of 28,521 MJ $ha^{-1}$ stemming from butane (70%) and diesel (19.14%) as primary sources. Indirect energy consumption was estimated at 45749 MJ $ha^{-1}$ and generated principally through the use of fertilizers (60%). Energy indices (efficiency, profitability and productivity) were estimated at 1.54, 0.54, and 0.45 kg $MJ^{-1}$, respectively. GHG emissions were found to be 3.47 t $CO_{2eq}$ $ha^{-1}$ in the production of onions and 3.63 t $CO_{2eq}$ $ha^{-1}$ for potatoes. We find that within the study area, increases in the size of production plots are not necessarily consistent with increases in energy use efficiency.

**Keywords:** energy analysis, energy consumption, onions, potatoes, energy indices, GHG emissions

## 1. Introduction

A continued desire to ensure food security in the face of sustained population growth has been one driving force in the process of agricultural innovation. At the same time, however, agricultural technology development and adoption have led to an increase in energy-dependence, and particularly so in terms of fossil fuels. In environmental terms, issues of sustainability in energy resource use lie in their non-renewable nature, and in the negative externalities generated by their use, particularly in terms of contribution to global warming through the emissions of greenhouse gases (GHGs). It has been estimated that 24% of 2010 global greenhouse gas emissions emanated from the agriculture sector (cultivation of crops and rearing of livestock) and exacerbated by deforestation. This estimate does not include the $CO_2$ that ecosystems beneficially remove from the atmosphere through the sequestration of carbon in biomass, dead organic matter and soils, and through which, approximately 20% of emissions from the agricultural sector are offset (Hillier et al., 2011; Vermeulen et al., 2012; Thornton, 2012).

Energy is a critical issue in food security, but one which is often overlooked. Energy efficiency is defined as "the ability of producing the same level of output with minimum used resources" (Sherman, 1988 quoted

Mousavi-Avval et al., 2012). While this is of critical importance for profitability at the farm gate, national level concerns related to energy efficiency use naturally include a desire for reduction in imports, with implications for foreign exchange, mitigation of greenhouse gas emissions and more specifically for this paper, competitiveness of the agricultural sector through a reduction in production costs.

Energy related challenges are of both historical and contemporary concern to Morocco given that the Kingdom imports 97% of its energy needs. Recognizing this vulnerability, Morocco has recently launched a number of national plans and programs aimed at promoting energy use efficiency in all economic activities, including agriculture, and through encouraging and incentivizing the use of renewable energy sources. Studies analyzing energy consumption, and evaluating energy efficiency of agricultural production in Morocco, are essential in order to inform the discovery of avenues for generating and disseminating knowledge on (energy) efficient and sustainable agricultural production practices which embody desired economic incentives. This study is placed within this context, with an overall objective to assess energy consumption (*i.e.*, testing if farmers producers are using energy unnecessarily excessively and if so, why are they using energy excessively/or inefficiently, and finally what measures can be taken to increase energy efficiency use and reduction of GHG emissions by these systems?) in the production of onions and potatoes two nationally important agricultural commodities produced within the province of El Hajeb.

## 2. Methodological Approach

### *2.1 Crops Selection and Study Area*

This study was undertaken within the province of El Hajeb, which is well known within Morocco for its historical importance in the production of onions and potatoes. Indeed, these crops represent 41% and 32% respectively of the area under vegetable production within the province, with a corresponding share of 52% and 33% in terms of market production for all vegetables. More broadly, areas under cultivation of onions and potatoes are found to be 60% and 38% of the total area these crops at the regional level (Meknès-Tafilet) and 16% and 8% nationally (DSS, DRA Meknès-Tafilalet, DPA El Hajeb, 2014). For the kingdom as a whole, onions and potatoes represent 13.33% and 21% of the areas devoted to vegetable production. Similarly, at the regional level, these two crops combined command 35% and 44% of the market shares for all cash crops.

### *2.2 Data Collection and Calculation Method*

While data related to the area under onions and potatoes is available for public consumption, data on the number of producers is conspicuously absent. We therefore opt for sampling at a single level of stratification, and more specifically at the level of district within the province of El Hajeb. More specifically, our stratification employs aggregated data from 3 districts within the study area: Ain Taoujtate, Agourai and El Hajeb (Note 1), with the number of growers chosen within each district determined by:

$$N_i = (S_i/S) \times N \qquad (1)$$

Where,

$N_i$: Number of growers to investigate in district i; $S_i$: area under vegetables within district i; S: area under vegetables within El Hajeb province; N: total number of growers to investigate.

A survey of 60 vegetable growers, with individuals randomly drawn from each district (El Hajeb, Ain Taoujtate and Agourai) was administered within the 2012/2013 cropping season. The questionnaire was designed in a manner such that contextual practices and limited time in administration were considered in the collection of data on energy inputs and outputs for each crop. Analysis of data was undertaken through utilization of PLANET balance (Method of Energy Analysis of Operations). As a tool designed for measuring fossil energy consumed directly or indirectly through inputs into a system, PLANET has generally been utilized for estimating GHG emissions at the scale of a farm (Figure 1) and taking into account both crop and livestock systems.

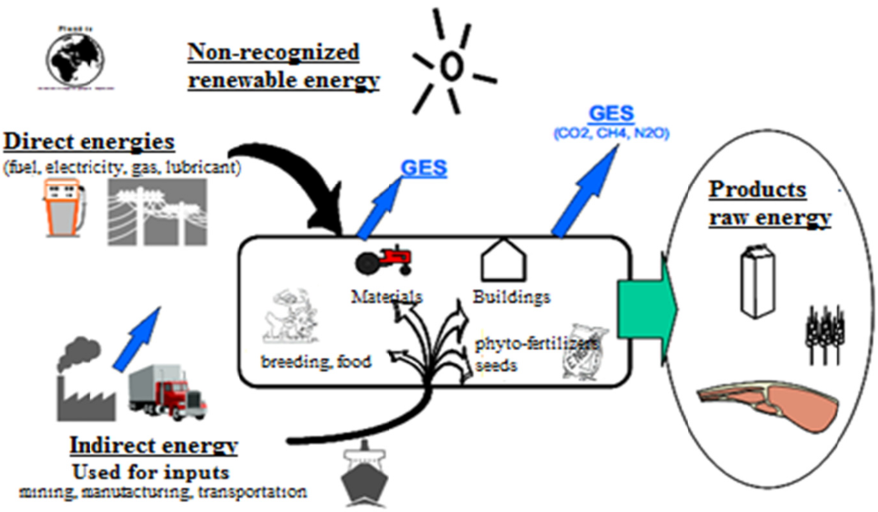


Figure 1. General diagram of PLANET balance

Source: Bochu (2007).

The underlying principle is one of converting physical quantities of inputs and outputs into units of MJ (Mega Joule) and evaluated on the basis of energy consumed and emitted per hectare. These coefficients and factors are consistent with international standards of life cycle analysis and environmental audits (Bochu, 2007). Conversion calculations were undertaken according to the following formula:

$$E_i/o = Q_i \times EE_i \quad (2)$$

Where,

$E_i/o$: Energy of specific input or output (MJ); $Q_i$: Physical quantity of the specific input or output (unit); $EE_i$: Equivalent unit of energy of the specific input or output (MJ/unit).

The specific sequence of steps of energy analysis followed were:

- Analysis of energy consumption (direct and indirect energy);
- Establishment of the energy balance (energy consumption and production);
- Assessment of energy performance; and
- GHG emission estimation and evaluation of global warming potential.

This analysis was conducted for each crop taking into account the class of producer. For the production of onions and potatoes, energy inputs are divided into direct and indirect sources of energy. Direct energy (ED) sources are those consumed on the production site, while indirect energy (EI) is that consumed during manufacturing process and transportation of inputs; in other words, EI corresponds to energy incorporated into factors which are generally outside of the farm gate.

Direct energy includes petroleum products and electricity used to produce each studied crop. Petroleum products include diesel (EG) utilized by agricultural machinery for the implementation of various agricultural operations (land preparation, phytosanitary treatments, etc.); butane (EB) used in irrigation water pumping; and gasoline (EE) used as a fuel for engines in the application of phytosanitary treatments (largely in spraying). Electricity (EEL) is also used to pump irrigation water within the area of study and included within the category of direct energy.

Indirect energy includes those embodied in seeds (ES), irrigation water (ACS), manure (EF), mineral fertilizers (EEM), phytosanitary treatments (FTEs) and agricultural machinery (EM). Energy utilized in irrigation is considered indirect when it relates to the conveyance of water to the plot as well as in the maintenance of equipment and irrigation canals (cleaning, maintenance, etc.). For mineral fertilizers, known to be major consumers of energy in the production process, we consider nitrogen, phosphorus, potassium and sulfur. Energy coefficients take into account mining, formulation, packaging, transport and distribution of these nutrients (Bochu, 2007).

Energy sequestered in agricultural machinery represents energy incorporated in commodities, manufacturing energy, repair and maintenance (Mousavi-Avval et al., 2012). Its equivalent energy matches the energy payback timeline (AE) which is measured through the following equation:

$$EE = AE = (M \times EA)/CTA \tag{3}$$

Where,

AE: Energy amortization schedule; M: The mass of the machine in kg; EA: Equipment annual energy; CTA: The annual work capacity h/year.

Energy balance consists of energy inputs which are comprised of consumed energy (direct and indirect) and energy outputs or emitted energy. For onion and potato production, outputs include yields of bulb (onion) and tubers (potato) which are converted to mega-joules. Based on obtained energy equivalents, we proceed with the evaluation of performance of energy utilized in the production of onions and potatoes through the creation of relevant indices: energy ratio, energy productivity, energy intensity, energy profitability and net energy gain.

The energy ratio (ER), also called Energy Efficiency Index, is the ratio of energy emitted to energy sequestered in production factors. This index indicates the influence of inputs expressed in the energy unit of energy output. The energy ratio in a system can be improved by reducing the energy sequestered in inputs and/or through reducing losses by increasing production yields (Kitani, 1999 quoted by Mousavi-Avval et al., (2012).

$$ER = \frac{\text{Total produced energy (MJ·ha}^{-1}\text{)}}{\text{Total consumed energy (MJ·ha}^{-1}\text{)}} \tag{4}$$

Energy productivity (ECD) is a measure of the amount of product obtained per unit of input energy. It is therefore calculated as the ratio between the energy expended in directly producing crop yield and total consumed energy:

$$ECD\ (\text{kg·MJ}^{-1}) = \frac{\text{Crop yield (kg·ha}^{-1}\text{)}}{\text{Total consumed energy (MJ·ha}^{-1}\text{)}} \tag{5}$$

Specific energy (SE) is the inverse of energy productivity and corresponds to the energy value required for an emitted unit of output:

$$SE\ (\text{kg·MJ}^{-1}) = \frac{1}{\text{ECD (kg·MJ}^{-1}\text{)}} = \frac{\text{Consumed energy (MJ·ha}^{-1}\text{)}}{\text{Crop yield (kg·ha}^{-1}\text{)}} \tag{6}$$

Net energy gain (NEG) is the difference between the energy expended in delivering output the total energy required in producing output:

$$NEG\ (\text{MJ·ha}^{-1}) = \text{Total produced energy (MJ·ha}^{-1}\text{)} - \text{Total consumed energy (MJ·ha}^{-1}\text{)} \tag{7}$$

Energy profitability (EPB) is defined as:

$$EPB = \frac{\text{NEG (MJ·ha}^{-1}\text{)}}{\text{Total consumed energy (MJ·ha}^{-1}\text{)}} \tag{8}$$

GHG emissions in the production of onion and potato are produced through both direct and indirect consumption of energy with CO2 and N2O as principal components. Quantifying emissions of each of these gases is undertaken on the basis of global warming potential and representing the total weight of estimated gas quantities:

$$1 \text{ ton } CO_2 = 1 \text{ equivalent tons of } CO_2 \tag{9}$$

$$1 \text{ ton of } N_2O = 310 \text{ equivalent tons of } CO_2 \tag{10}$$

## 3. Results and Discussion

### *3.1 Energy Analysis in the Production of Onions*

#### 3.1.1 Direct Energy Consumption

Based on energy equivalence, the average direct energy consumption for all respondent onion producers is approximated at 72135 MJ/ha. Taking each energy item separately, respondent producers consumed an average of 57334 MJ/ha of butane, 7424 MJ/ha of diesel, 6920 MJ/ha of electricity and 457.2 MJ/ha of gasoline.

Based on these empirical results, the main component of direct energy consumption in the production of onions is Butane. It represents 79.48% of total direct energy consumption. This is followed by diesel (10.29%), electricity (9.59%) and lastly gasoline (0.63%). The high proportion occupied by butane in total direct energy consumption is due to its ubiquitous use in the pumping of water for irrigation, but incentivized by significant subsidies which have been targeted for household cooking purposes. In Aval and Moghaddam (2013) and Barber (2004), research undertaken in Iran and New Zealand respectively, direct energy utilized in the production of onion are diesel and electricity. Butane, which is the main source in direct (subsidized) energy consumption for onion production in Morocco, is not generally utilized in other countries and signals a need for policy dialogue in Morocco in terms of both subsidy reform, as well as in terms of moving towards cleaner uses of energy.

Irrigation, as a source of direct energy, consumes an average of 68212 MJ/ha or 94.56% of total consumption. This is followed by the process of land preparation, consuming 3209 MJ/ha; and thereafter phytosanitary treatment processes which utilize 714.96 MJ/ha. In terms of production costs, irrigation maintains a significant proportion (20%); hence the need for rationalizing irrigation practices in technical terms (speed, duration, frequency) so as to ensure a better allocation of both water and energy resources for both productivity and efficiency purposes.

Our results indicate that total direct energy consumption follows an upward trend with increasing plot size. Indeed, 'small' onion producers with plots of less than 2 hectares consume the least amount of energy (41895 MJ/ha), with those between 2 and 5 hectares consuming 66180 MJ/ha; and 67897 MJ/ha in consumption for producers in the 5 to 10-hectare plot size range. 'Large' producers with parcels exceeding 10 hectares consume in excess of 2.5 times smaller producers, with estimates as high as 104065 MJ/ha within the sample. We suggest that these very large variances are most likely a reflection of the different weights of energy utilized in pumping irrigation water and in terms of conveyance systems utilized in the delivery of water to the crop.

3.1.2 Indirect Energy Consumption

Indirect energy utilized in the production of onions consists of energy sequestered in the factors of production; namely seeds, mineral fertilizers, phytosanitary treatments, water irrigation and farm equipment. The average consumption of indirect energy for all surveyed onion producers was estimated at 35348 MJ/ha and by component: 21749 MJ/ha in mineral fertilizers, 10624 MJ/ha in irrigation water, 2020 MJ/ha in farm equipment, 839 MJ/ha in phytosanitary treatments and 116 MJ/ha in seeds. However, the main sources of indirect energy consumed in the production of onions are mineral fertilizers (61.53%) and irrigation water (30.05%). These are followed by agricultural equipment (5.71%), phytosanitary treatment (2.37%) and seeds (0.33%).

With respect to mineral fertilizers, nitrogen is most prominent and with consumption estimated at 17062 MJ/ha or 78.45% of total fertilizer consumption. This is followed by phosphorus at 3778 MJ/ha or 17.37% of total fertilizer consumed, with energy consumption of potassium and sulfur not of (relatively) significant value, but estimated at 715.1 MJ/ha and 19.66 MJ/ha respectively. In comparing the results of the use of indirect energy obtained in this study with those reported by Aval and Moghaddam (2013) and Barber (2004) in Iran and New Zealand, there is general consistency in a claim that mineral fertilizers are key consumers of indirect energy in vegetable production; together with a more specific claim that Moroccan producers are relatively greater consumers of energy in the application of mineral fertilizer in onion production.

In terms of energy consumption in the conveyance and application of irrigation water, Moroccan producers would appear to consume greater quantities relative to Iranian producers of onions and potatoes. Indeed, the level of consumption of the indirect energy is 12174 MJ/ha in Morocco and 10624 MJ/ha in Iran (Aval and Moghaddam, 2013). The government of Morocco has placed much policy interest on providing incentives to farmers to adopt drip irrigation as a water saving practice, together with ancillary benefits related to improved quality and yield. While a significant number of farmers have adopted drip irrigation, anecdotal evidence from the field would suggest that farmers continue to apply significantly more water than is technically in the production of both onions and potatoes. One explanation for this relates to heavy subsidies on butane, to support households in lowering the cost of cooking fuels, but in practice equally important for farm households in the pumping of irrigation water. Another relates to efficacy in extension service provision and knowledge dissemination. While a significant national strategy for reforming extension services in Morocco has been designed and is in process, there have been notable delays in implementing the plan; and concerns related to overlapping of mandates across a number of organizations which may lead to institutional conflict (Note 2).

Regarding the energy embedded within the category of phytosanitary treatments, Iranian producers consume 1192 MJ/ha while Moroccan producers use approximately 839 MJ/ha (Aval & Moghaddam, 2013). In large part, this is due to a greater number of treatments, with Iranian producers applying an average of 6.2 relative to 3.7 for Moroccan producers. The breakdown of energy consumed according to the type of treatment indicates that Iranian farmers apply more herbicides and insecticides while Moroccan farmers tend to use more fungicides. In New Zealand, onion growers consumed 12050 MJ/ha in phytosanitary treatments (Barber, 2004) for the

2000/2001 cropping season. This figure, however, should be viewed with caution as the author reports that the season under study was exceptionally unique given heavier than average rainfall and significant humidity.

On average, Barber (2004) suggests that a normal use of fungicides is 20 to 25 percent of the calculated amount. The vagaries of weather, therefore, may play a key role in the amount of energy utilized in phytosanitary treatments. Equally important are on farm storage and drying practices which may result in the greater use of fungicides. To be sure, a standard practice on Moroccan farms, within the area of study, is to dry onions under stone mounds which are covered with straw. The incidence of mould and fungus is therefore potentially high in the absence of controlled environments for storage, and thereby resulting in greater need for applications of phytosanitary treatments.

For producers with land areas of less than 2 ha indirect energy consumption was estimated at 29460 MJ/ha. For producers with plot sizes between 5 and 10 ha, consumption was estimated at 46342.58 MJ/ha. Producers with land holdings of greater than 10 ha consumed approximately 12% in energy consumption relative to the middle class of producers. In all cases, mineral fertilizer consumption was the key input into indirect energy consumption and accounting for close to 62% of total indirect energy consumed.

### 3.1.3 Energy Balance

Average energy consumed across the sample was estimated at 107483 MJ/ha for onions with the amount of energy emitted at 84269 MJ/ha. Direct energy accounted for 67.11% of admissions with indirect energy accounting for the remainder of 32.89% of total energy consumed.

Of the total energy consumed, on average across all sampled onion producers, 53.34% was generated from the use of butane and 20.24% from the use of fertilizer. Initiatives aimed at reducing energy use in the production of onions within the area of study would achieve much impact, therefore, if concentration was placed upon efficient and rational use of these two inputs. A need for policy dialogue on existing subsidies is clearly evident from these results, particularly in terms of butane subsidy, but equally important in terms of delivering more effective knowledge and information to farmers on the effective use of fertilizers through both reduction as well as in more effective water saving irrigation technologies.

Table 1. Energy balance in the production of onions within the Meknes region

| Items | | < 2 ha | [2,5] ha | [5,10] ha | ≥ 10 ha | Total sample | % energy input |
|---|---|---|---|---|---|---|---|
| *Energy inputs* | | | | | | | |
| Direct Energy | Diesel | 7 212.94 | 4 891.27 | 11 581.00 | 4 748.33 | 7 424.01 | 6.91 |
| | Gasoline | 138.33 | 329.04 | 520.64 | 937.21 | 457.19 | 0.43 |
| | Butane | 34 544 | 60 960.00 | 50 319.71 | 69 951.60 | 57 333.93 | 53.34 |
| | Electricity | 0.00 | 0.00 | 5 475.27 | 28 428.33 | 6 920.14 | 6.44 |
| | *Total* | *41 895.28* | *66 180.30* | *67 896.62* | *104 065.48* | *72 135.27* | *67.11* |
| Indirect Energy | Seeds | 88.20 | 98.70 | 144.33 | 148.23 | 115.40 | 0.11 |
| | Fertilizers | 16 037.98 | 16 535.42 | 32 495.78 | 28 528.30 | 21 749.48 | 20.24 |
| | Phytosanitary | 609.52 | 710.39 | 990.17 | 1 174.67 | 839.41 | 0.78 |
| | Irrigation water | 11 179.20 | 11 120.62 | 10 556.81 | 9 193.60 | 10 623.76 | 9.88 |
| | Materials | 1 545.36 | 1 894.95 | 2 155.49 | 2 166 | 2 020.01 | 1.88 |
| | *Total* | *29 460.27* | *30 360.09* | *46 342.58* | *41 210.79* | *35 348.05* | *32.89* |
| Total energy consumed | | 71 355.55 | 96 540.39 | 114 239.20 | 145 276.27 | 107483.31 | 100 |
| Total energy emitted | | 74 755.56 | 77 678.57 | 82 254.55 | 108 629.17 | 84 269.17 | - |

Source: Own elaboration from Survey (2015).

### 3.1.4 Energy Performance Indices

The calculation of energy performance indices for the survey sample indicates that the energy ratio is less than 1, with negative profitability. One MJ of energy converts to 0.54 kg of onion or put differently, one kilogram of onion requires 1.85 MJ of energy. Analysis by plot size reveals that smaller producers have the best values of these indices and is likely a reflection of lower input levels as well as relatively low levels of mechanization.

Scale of farm operation, therefore, is likely to increase energy consumption per kilogram of output rather than inducing efficiency in energy utilization.

3.1.5 GHG Estimation

Key greenhouse gases emitted in the production of onion are carbon dioxide ($CO_2$) and Nitrous oxide ($N_2O$) with emission values of 2.68 t/ha and 2.54 kg/ha respectively. From empirical findings, 79% of $CO_2$ emissions accrue from the use of mineral fertilizers, 9% from the combustion of butane in the pumping of irrigation, 6% in the manufactory of agricultural equipment, 3% in the use of electricity for irrigation, 2% in the combustion of diesel (land preparation, irrigation and spraying of phytosanitary treatment) and 1% when in the application of pesticides.

In the case of mineral fertilizers, almost all of the emission (more than 99%) is a result of energy consumed in the manufacturing stage as opposed to application on farm. Transforming these emission values into global warming potential (GWP), expressed as $CO_2$ equivalent ($CO_{2eq}$), our results indicate that onion production has a potential for atmospheric warming of approximately 3.467 t $CO_{2eq}$/ha within the study area. Carbon dioxide ($CO_2$) contributes 77.29% to the potential for global warming with an average of 2.68 $CO_{2eq}$ /ha while Nitrous oxide ($N_2O$) contributes approximately 22.71% in GWP through its emissions of 0.78 t $CO_{2eq}$/ha. As expected, global warming potential increases with larger plot sizes.

*3.2 Energy Analysis in the Production of Potatoes*

3.2.1 Direct Energy Consumption

An analysis of the use of direct energy in potato production indicates a total consumption of 28521 MJ/ha. The average consumption of each component was found to be: 19964 MJ/ha for butane, 5458 MJ/ha for diesel, 2608 MJ/ha for electricity, and 490 MJ/ha for gasoline. In terms of consumption as percentage of total energy consumption: Butane (70%), followed by gas oil (19.14%), electricity (9.14%), and finally gasoline (1.72%).

From the perspective of agricultural production, we find that the most energy-intensive activity is irrigation (84.35%), followed by land preparation (11.56%), phytosanitary treatment (3.05%) and finally the maintenance of the cultivation and harvesting equipment with 0.52% each. Comparing the results of this study with those of Mohammadi et al. (2008), Ghahderijani et al., (2013), Barber (2004) and Pimentel et al. (2002), cited by Barber, 2004), it would appear that butane is not used by Iranian, New Zealand and US potato producers in the pumping of irrigation water, while it represents the main direct energy consumption item for Moroccan producers. For Iran, the only direct conventional power/energy source considered in relatively recent studies is diesel (Mohammadi et al., 2008; Ghahderijani et al., 2013). This source of energy is largely consumed during the land preparation, planting, irrigation, application of phytosanitary treatments, fertilization and harvesting.

In the Iranian province of Ardabil, diesel consumption was estimated at 12897 MJ/ha and in Esfahan province at 5638 MJ/ha (Ghahderijani et al., 2013). In Morocco, average diesel consumption was estimated at 5458 MJ/ha but is not the only choice of fuel for pumping of water in potato production. In New Zealand and the United States, the sources of direct energy used in potato production are diesel and electricity, with diesel used in all cultivation operations. Its consumption for 294 L/ha in New Zealand is 11966 MJ/ha, for 424 L/ha in the United States is 17257 MJ/ha and for 134 L/ha in Morocco is 5458 MJ/ha. These results indirectly reflect the degree of mechanization of the production of potatoes in each country. With respect to electricity, consumption in New Zealand was estimated by the authors (ibid) at 360 KWh/ha or 3456 MJ/ha; in the US, it is 47 kWh/ha or 451 MJ/ha; and in Morocco we estimate this to be 272 KWh/ha or 3 973 MJ/ha. Several variables generate these differences in energy consumption. These include: the source of irrigation water (water pumped and surface water), annual rainfall, farmers' practices, and the depth of groundwater, among others.

As expected, direct consumption of energy increases with increasing plot size. Indeed, the producers of small producers, with plot sizes under 2 hectares consume 16449 MJ /ha, while, those with plots between 2 and 5 hectares consuming 29049 MJ/ha, and 34083 MJ/ha for those with plots sizes of between 5 and 10 hectares. Farm sizes exceeding 10 hectares consumes 46561 MJ/ha of direct energy. The energetic study undertaken by Ghahderijani et al. (2013) in Iran was also conducted according to the field sizes, with small producers classified on the basis of less than 1 ha, medium producers with an areas between 1 and 5 ha and large producers with an areas greater than 5 hectares. Their analysis in Iran indicate a contrary observation: energy consumption decreases with an increase of field size. Indeed, small producers reach average consumption levels of 50549 MJ/ha, the medium 44796 MJ/ha and the large ones consume about 42963 MJ/ha. Iran, therefore, has an economy of scale in energy consumption with increasing field sizes while Morocco is experiencing dis-economies of scale at this level.

3.2.2 Indirect Energy Consumption

Sources of indirect energy in the production of potato are: seeds, irrigation water, fertilizer (chemical fertilizers and organic manure), phytosanitary treatments, agricultural machinery, straw and plastic (for pre-germination treatment). Average indirect energy consumption was estimated at 45749 MJ/ha. The main energy consumption items are: fertilizers (27241 MJ/ha; 59.54%), seeds (9682 MJ/ha; 21.16%) and irrigation water (4672 MJ/ha; 10.21%).

Energy sequestered in fertilizers is largely due to the use of nitrogen (81.59%) containing 22227 MJ/ha, followed by phosphate 12.65% used up to 3445 MJ/ha, then potassium (4.72%) and finally manure (0.8%) and sulfur (0.2%) with quantities that are relatively small (228 MJ/ha and 58 MJ/ha, respectively).

Comparing the results of this study with those of Iran, New Zealand and the United States, it appears that in all these countries, the largest single consumer of indirect energy is fertilizer. Seeds were not considered in the study of Barber (2004) for New Zealand while it occupied the second largest item of indirect energy consumption for studies in the US and Iran. The energy sequestered in irrigation water was also not included in studies in New Zealand and for the USA. For Iran, energy consumption in the conveyance and application of irrigation water was placed in third after fertilizers and seeds. Nitrogen represented the key element within all studies in relation to the category of fertilizer.

Indirect energy consumption increases with an increase in plot size as expected. Indeed, the smaller holdings (less than 2 ha) consume 41801 MJ/ha, while those between 2 and 5 ha consume 44815 MJ/ha; larger areas between 5 and 10 ha use 49353 MJ/ha and those exceeding 10 hectares consume 53328 MJ/ha.

3.2.3 Energy Balance

We find that average energy consumption for the entire sample per hectare of potatoes is in the range of 74270 MJ/ha and the amount of emitted energy per hectare estimated at 114634 MJ/ha (Table 2). The structure of energy consumption is dominated by indirect energy representing 61.60% of total consumption with the balance of 38.40% as consumption of direct energy.

Table 2. Energy balance in the production of potatoes within the Meknes region

| Items | | < 2 ha | [2,5] ha | [5,10] ha | ≥ 10 ha | Total sample | % energy input |
|---|---|---|---|---|---|---|---|
| *Energy inputs* | | | | | | | |
| Direct Energy | Diesel | 3 034.00 | 7 063.49 | 4 431.78 | 6 410.25 | 5 458.43 | 7.35 |
| | Gasoline | 226.36 | 468.95 | 617.89 | 1 037.50 | 490.45 | 0.66 |
| | Butane | 13 189.53 | 20 147.28 | 22 487.47 | 32 004.00 | 19 964.40 | 26.88 |
| | Electricity | 0.00 | 1 369.98 | 6 546.00 | 7 110.23 | 2 608.06 | 3.51 |
| | *Total* | *16 449.89* | *29 049.70* | *34 083.13* | *46 561.98* | *28 521.34* | *38.40* |
| Indirect Energy | Seeds | 9 545.45 | 9 600.00 | 9 888.89 | 10 000.00 | 9 681.82 | 13.04 |
| | Fertilizers | 23 488.52 | 26 690.86 | 30 220.19 | 33 602.66 | 27 240.53 | 36.68 |
| | Phytosanitary | 329.78 | 436.22 | 574.81 | 621.23 | 454.77 | 0.61 |
| | Irrigation water | 5 054.01 | 4 506.36 | 4 724.19 | 4 329.90 | 4 671.79 | 6.29 |
| | Materials | 1 423.56 | 1 610.35 | 2 006.34 | 2 720.90 | 1 730.71 | 2.33 |
| | *Total* | *1 520.59* | *1 529.28* | *1 504.50* | *1 593.00* | *1 527.83* | *2.06* |
| | Seeds | 439.09 | 441.60 | 434.44 | 460.00 | 441.18 | 0.59 |
| | Fertilizer | 41 801.01 | 44 814.68 | 49 353.37 | 53 327.69 | 45 748.63 | 61.60 |
| Total energy consumed | | 58 250.90 | 73 864.37 | 83 436.50 | 99 889.67 | 74 269.97 | 100 |
| Total energy emitted | | 107 263.64 | 115 575.00 | 119 983.33 | 118 162.50 | 114 634.09 | - |

Source: Own elaboration from Survey (2014).

We note that 76.59% of the average energy consumption of all interviewed potato producers are divided between "fertilizers" (36.68%), "butane "(26, 88%), and seeds (13.04%). These are therefore areas which are of key target for inducing energy-saving. Analysis by class of producers globally shows that the inputs and outputs increase with the size of the plots and consistent with our results.

3.2.4 Energy Performance Indices

The net energy gain of the entire sample is positive and equals 40364 MJ/ha. One MJ of energy per hectare is required to produce 0.45Kg of potatoes, or put differently, 1 kilogram of potato emitted requires 2.24MJ of energy. Analysis by plot class reveals that small producers have the best values of these indices relative to larger producers. This is largely due to their relatively lower use of agricultural inputs and relatively low level of mechanization.

3.2.5 GHG Estimation

The main greenhouse gases emitted in the production of potatoes are carbon dioxide $CO_2$ and nitrous oxide $N_2O$, with emission estimates of 2.61 t/ha and 3.30 kg/ha, respectively. Based on the empirical results, approximately 84.67% of $CO_2$ emissions come from mineral fertilizers, 6.63% from agricultural equipment, 3.37% from butane, 2.89% from organic manure, 1.46% from diesel combustion, 0.05% from phytosanitary products, and 0.46% from plastic used to stimulate the germination of potato tubers.

By transforming its emissions in global warming potential (GWP), expressed as $CO_2$ equivalent ($CO_{2eq}$), the results indicate that potato production has potential for atmospheric warming of approximately 3.628 $CO_{2eq}$ /ha. Carbon dioxide ($CO_2$) contributes 71.82% in the potential of global warming with an average of 2.61 $CO_{2eq}$ /ha while $N_2O$ Nitrous oxide contributes 28.17% in GWP with emissions of 1.02 $CO_{2eq}$ /ha. Comparing between different classes of the producers on GWP, we note that GWP reported per hectare increases with the increase in the size of the plots as expected.

## 4. Concluding Remarks and Recommendations

Energy is essential for food security and development. However, food production and current energy use patterns may no longer be viable in the long term given current rates of natural resource extraction. Given that energy use in agriculture is related to crop choices and management practices within the production process, a diagnosis such as that undertaken within this study may allow decision makers and farmers to consider mutually consistent incentives in the adoption of energy saving practices; thereby contributing to direct improvements in energy efficiency and (indirectly induced) reductions in greenhouse gas emissions stemming from agricultural production.

Studies on energy analysis of agricultural productions in Morocco are limited; reflecting a significant shortfall in research. Vegetable crops are among the most intensive agricultural production inputs including energy resources. This study has analyzed energy consumption for two vegetable crops: onion and potato in El Hajeb province of Meknes.

The results of energy analysis in onion production suggest that total energy consumption is 107483 MJ/ha and divided into direct energy (67.11%) and indirect energy (32.89%), with butane (79.48%) as the main source of direct energy consumption. Significant indirect energy consumption items were found to be mineral fertilizers (61.53%) and energy used in the pumping of irrigation water (30.05%). Total energy emitted was estimated at 84269 MJ/ha. Empirical findings from energy analysis in the production of potatoes indicate total energy consumption of 74270 MJ/ha. This is divided into direct energy (38.40%) and indirect energy (61.60%) with Butane (70%) as the main source of direct energy. Significant indirect energy was found to be consumed in the form of fertilizers (59.54%), seeds (21.16%) and pumping of irrigation water (10.21%). Energy production (emitted) in potato production was estimated at 114634 MJ/ha.

An analysis of energy performance indices indicates that energetic efficiency, profitability and productivity are 0.78, 0.22 and 0.54 kg/MJ, respectively for onion and 1.54, 0.54 and 0.45 kg/MJ for potato. The analysis of GHG emissions suggests that global climate warming potential is about 3.47 $CO_{2eq}$/ha for the production of onion and 3.63 $CO_{2eq}$/ha for potato production. Fertilizers, and particularly nitrogen, were found to be significant emitters of greenhouse gas emissions. One key learning is that for both onion and potato, energy consumption increases with an increase in the size of farm plots and standardized on a per hectare basis. This is different from the experience of Iranian producers, as detailed within the literature, and signals that there may be little savings in energy through expansion in the scale of production. It appears, therefore, that larger farm operations within the study area are not necessarily more energy efficient relative to smaller production units. This is an important policy related finding, and one which requires more in depth understanding of the nature of incentives provided through subsidies such as butane, as well as within a general movement towards consolidating fragmented land parcels.

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**Notes**

Note 1. El Hajeb province is administratively divided into 16 districts, of which one district is also named El Hajeb.

Note 2. Based on information gathered in the field and through interviews with key officials within existing public extension services.

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