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Assessing the Effect of Global Climate Change on the Future Jordanian Society (I): A Mathematical Model

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ABSTRACT

A calculation model was developed to forecast and assess the effect of global climate change on the future of energy use, water sufficiency and agricultural production in Jordan. For the purpose of this study, the world is divided into three regions: Jordan, Arab League countries and the rest of the world. Interaction between these regions is assumed to take place in the form of agricultural products exchange. Considering the sectors of energy, water and agriculture in Jordan from the viewpoint of systems' concepts, the future behaviors of their quantities are formulated under conditions of climate change. These quantities are: energy consumption, water supply and demand, and the production and consumption of agricultural products. An example calculation is made and the behavioral features of those quantities from the year 2000 to 2100 are derived under the constraint that the total amount of the worldwide production of a certain agricultural product is equal to the total amount of its consumption. The results show that the amounts of energy, water and agricultural products required for Jordan will become remarkably high, especially in the second half of this century. This strongly emphasizes the need for appropriate policies to tackle the deficits. The developed model appears suitable for assessing the adequacy of the policies that should be implemented in future Jordan regarding the management of the sectors of energy, water and agriculture.

KEYWORDS: Calculation model; future Jordanian society; global climate change; energy; water; agriculture; assessment; forecast; policy making.

1. INTRODUCTION

Population growth and consumption demand in developing countries are subjects of great concern for planners and strategy makers. An example on the difficulty of sustaining sufficient resources to match population growth is the water shortage in the basin of the Tigris and Euphrates, due to the drastically reduced flow rate of the two rivers which is caused by increased population and environmental changes (McCarthy et al., 2001). Also, due to population growth in India, the use of underground water has been restricted. Moreover, it has been long time since water deficiency has been reported in China due to the same reason (McCarthy et al., 2001). Thus, in countries with high rates of population growth, the assurance of water resources has grown to become a significant problem that can affect the growth of economy.

Meanwhile, since about a couple of decades, it has been widely accepted that the economic activities of mankind have caused a change in global climate due to the increased concentration of atmospheric CO_2. A recent calculation, using the world-wide model of climate change, has shown that an increase of CO_2 concentration to two times its present level can result in about two to five degrees Celsius increase in the average global atmospheric temperature. This temperature rise is associated with increased water precipitation in winter, and decreased one in summer, in middle and low latitude regions, respectively (McCarthy et al., 2001). It is obvious, therefore, that such global climate change has a direct influence on surface and ground water resources. Moreover, it has also been pointed out that there exists a possible positive link between vegetation and precipitation. Therefore, the multiplicative effect of the change of both, temperature and precipitation, may result in an extraordinary influence on the agricultural production and water resources.

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The destiny of developing countries in this century is thus governed by the double yoke of growing population and global climate change. Many investigations have been made in the last twenty years by the developing countries themselves, on what policies should be undertaken in the fields of energy-economics, water resources and agriculture (McCarthy et al., 2001; Schneider, Rosencranz and Niles, 2002). This also applies for Arab League countries, where many proposals have seriously been considered (Strzepek, Yates, and Quasy, 1996; El-Shaer et al., 1997; Yates and Strzepek, 1998; Alderwish and Al-Eryani, 1999; Strzepek and Yates, 2000; Alkolibi, 2002; Jury, 2002). Although the situation of the double yoke holds also for Jordan, there have been little serious investigations or concrete policies on the assurance of energy and water resources in future, despite the rapidly growing population.

One of the causes of such a situation in Jordan may be the lack of public awareness and the feeling of indifference towards the significance of the problem. Another conceivable cause could be the un-establishment of the methodology for forecasting the prospective status of Jordan. It is just at this point where a concrete model that can estimate the extent of deficiency of future energy and water resources, and assess the future trend of agricultural production in Jordan is needed.

In such a context, a methodology is developed here to enable the derivation of some information useful for making policies that can determine the Jordanian destiny in this century. In Sect.2, a general framework is shown, and in Sect.3 the model is described for the three sectors in Jordan; energy, water resources and agriculture. In Sect.4 the computational methods are given, followed by some example calculations in Sect.5. Conclusions are made in the last Sect.

2. GENERAL FRAMEWORK

The features of the change of global atmospheric temperature and water precipitation due to the increased CO_2 concentration is usually calculated using the so-called GCM (General Circulation Model) (Houghton et al., 2001). Since the extent of probable climate change in Jordan can not precisely be estimated by this model, the future values of the meteorological quantities will be treated as exogenous variables in our model, where it is intended to assess the influential effect of the climate change on energy, water and agriculture in future Jordan. The flow of data used in the model is schematically illustrated in Fig. 1.

The three sectors; energy, water, and agriculture in Jordan are dependent. They interact with each other and evolve with time. Due to the global climate change, various factors originating from this change affect the Jordanian systems of society and complicate the interaction and cause-and-result relations between the three sectors. Moreover, since those factors are of a global nature, they do not act only on the Jordanian systems but rather extend all over the world. And since all countries are, more or less, mutually interdependent, the future evolution of Jordan must be looked at within the context of the worldwide evolution. In this case, the variation of the effect of climate change from a certain region to another must be taken into consideration.

In many worldwide models, the world is usually divided into several regions which interact with each other by the exchange of energy, materials and information (Edmonds and Reilly, 1983; Edmonds et al., 1993; Manne, Mendelsohn and Richels, 1993; Nordhaus, 1994; Mori and Takahara, 1998). Likewise, in our model three interacting regions are proposed. These include Jordan, Arab League countries excluding Jordan, and other countries. Between these regions the interaction is assumed to take place only through the exchange of agricultural products.

The reason to consider Arab League as the second region is not only because Jordan is surrounded by the League countries, but also because the future destiny of Jordan in all aspects, including economy and politics, is more or less affected by the situation in the rest of League countries. On the other hand, statistical quantities with regard to the society and economy, which are required for the estimation of the third region, are those of OECD (Organization for Economic Cooperation and Development), considering the OECD group as a representative of that region. This is because the economy of Arab League countries, including Jordan, has been strongly influenced by OECD policies. Figure (2) shows this situation.

Although many quantities, such as, energy sources, materials, money, labor force, and information are also exchanged between the three regions, they are not explicitly modeled in our case for simplicity, although their effect is implicitly taken into the model through the following argument of homogenization.

With the worldwide exchange of those quantities, including agricultural products, it is certainly realized sooner or later the homogenization of the world. As for the manifestation of such global homogenization, one of the following three situations is supposed to occur for Jordan.

(1) Arabic countries can be roughly classified into two groups according to their economic growth. These are Oil-rich gulf countries, and the remaining countries with scarce oil production. The first scenario hypothesizes the growth of Jordanian society along the same trajectory of the latter group with respect to the relation between the per capita GNP (Gross National Product) G_c and the per capita energy consumption E_c. that means:

$$G_C \propto E_C^{\,0.36} . \qquad (1)$$

(2) The second scenario hypothesizes the growth of Jordan as the same as that of gulf countries along the trajectory:

$$G_c \propto E_c^{\,0.72} . \qquad (2)$$

(3) The third scenario assumes the growth of Jordan to be the same as that of OECD countries as:

$$G_c \propto E_c^{\,1.67} . \qquad (3)$$

Here, the exponents in these equations were determined by using actual features, which are given in Figure (3). Thus, the GNP in our model can be given in terms of the population at a certain time and the total amount of energy use at that time.

The future behavior of several statistical quantities is estimated by extrapolating them with the growing curve, in which constants are determined using their past trend, so that the curve most satisfactorily fits the past behavior. On the other hand, some constants are determined so that the results of model calculation in the retrospective direction in time most satisfactorily fit the actual values of the quantities in the past. Thus, after reducing the number of unknown variables by these procedures, calculation is made with some variables as scenario parameters or exogenous policy factors.

Although the calculations of energy use and water resources are made only for Jordan, the agricultural sector calculations are carried out for the three regions, between which the trade of agricultural products is assumed, such that the total worldwide production of a certain product is always equal to the total consumption of that product. No product stock is considered in this case. The treatment of each sector will be detailed later in the paper.

3. MODEL DESCRIPTION

3.1 Energy Sector

Three sub-sectors of the energy use in Jordan are considered here. These are the domestic use (which includes also the commercial and municipality use), the industrial use (which includes agriculture), and the transportation use. All energy sources are treated as one type of hypothetical energy source in units of tons of oil equivalence (toe). In this case, the process efficiency for the transformation of oil or gas into electricity is assumed to be 1/3. An energy flow diagram for Jordan is depicted in Figure (4).

Total energy consumption in Jordan $E_J(t)$ at a given time t, is given by the sum of the consumption of three sub-sectors, domestic ($E_d(t)$), industrial ($E_i(t)$), and transport ($E_t(t)$);

$$E_J(t) = E_d(t) + E_i(t) + E_t(t) \qquad (4)$$

$$\equiv \xi_d E_1(t) E_2(t) E_3(t) E_4(t) p_1(t) + \xi_i E_5(t) E_6(t) E_7(t) + \xi_t E_8(t) E_9(t) E_{10}(t) E_{11}(t), \qquad (5)$$

where the constant coefficients ξ_d, ξ_i and ξ_t are determined by the least squares method using the trend of secular variation of $E_d(t)$, $E_i(t)$ and $E_t(t)$ in the past. The quantity $E_1(t)$ is the temperature dependent factor of energy use in the domestic sector, and is given by

$$E_1(t) = 1 + C_{E1} \cdot \Delta T_1(t) , \qquad (6)$$

where, C_{E1} is a constant (=0.1/degree; estimated from the data cited in McCarthy et al. (2001)), and $\Delta T_1(t)$ is the temperature change due to global climate change. The quantity $E_1(t)$ corresponds to the expansion of the use of air conditioners, electric fans and similar equipment due to the increase of average temperature.

The quantity $E_2(t)$ is the income-dependent factor for the domestic energy use, which accounts for the effect of enhanced income on energy use. This is given by

$$E_2(t) = \left(G_{c1}(t) / G_{c1}(0)\right)^{\eta_1} , \qquad (7)$$

where $G_{c1}(t)$ is the per capita GNP in Jordan at t, $G_{c1}(0)$ corresponds to the calendar year 2000, and η_1 =0.775 (More and Takahashi, 1998) is the income elasticity of the energy use.

$E_3(t)$ is the energy-cost dependent factor for domestic sector energy use and is given by:

$$E_3(t) = \left(R_{Ed}(t) / R_{Ed}(0)\right)^{\eta_2}, \tag{8}$$

where $R_{Ed}(t)$ is the energy cost in the domestic sector, whose treatment will be shown later, and η_2 is its elasticity. It should be noted that in Jordan, the quantity $R_{Ed}(t)$ has been politically determined in the past depending on the economical supply-demand relationship. Such a policy may also be sustained up to a certain time in the future. The value of the elasticity η_2 is determined by using the secular data of $E_d(t)$ and $R_{Ed}(t)$ in the past using the method of least squares.

$E_4(t)$ is the energy saving factor originating from the improvement of energy use efficiency and the execution of energy saving in the domestic sector. This is estimated by the following growing curve function H (called hereafter the growth function):

$$E_4(t) = 1 + H(a_{E4}, b_{E4}, c_{E4} : t), \tag{9}$$

where

$$H(a,b,c:t) \equiv c\left\{1 \middle/ \begin{matrix} \left(1+\exp(-at+b)\right) - \\ 1/\left(1+\exp(b)\right) \end{matrix} \right\}, \tag{10}$$

a_{E4}, b_{E4} and c_{E4} being constant parameters.

The quantity $p_1(t)$ is the population in Jordan at a certain time and is given by the growth function as:

$$p_1(t) = P_1(0)\left(1 + H(a_{p1}, b_{p1}, c_{p1} : t)\right) \tag{11}$$

a_{p1}, b_{p1} and c_{p1} being constants which must be determined by using the secular data in the past.

The $E_5(t)$ is a factor to cater for the effect of increased energy use with the increased industrial productivity. To determine this factor, one of the following two options is applied in our model.

(1) The increased industrial productivity trend in the future is estimated by extrapolating past trend using a growth function:

$$E_5(t) = E_5(0)\left(1 + H(a_{E5}, b_{E5}, c_{E5} : t)\right). \tag{12}$$

(2) Although the industry share of GNP in Jordan has only been a portion of the total GNP, the following form is used for estimating $E_5(t)$ by assuming that the industrial productivity will become proportional to the per capita GNP in the future;

$$E_5(t) = \left(G_c(t)/G_c(0)\right)^{\eta_3}, \tag{13}$$

where η_3 =0.85 (Mori and Takahashi, 1998) is the elasticity. Equation (13) is the one to be used in the example calculation.

$E_6(t)$ is the energy-cost dependent factor for the use of energy in the industrial sector. This is also assumed to be given by a form similar to Equation (8)

$$E_6(t) = \left(R_{Ei}(t)/R_{Ei}(0)\right)^{\eta_4}, \tag{14}$$

where the elasticity η_4 is, again, determined by using the secular data of the relevant quantities in the past. $E_7(t)$ is the energy saving factor in the industrial sub-sector, for which the similar form as $E_4(t)$ is assumed.

In deriving the factors in the third term of the right hand side of Equation (5), which corresponds to the transportation sector, it is assumed that cars will continue to be predominant transport mean in the future. The energy consumption growth is, therefore, assumed to take the same trend of that of the cars growth. The factor $E_8(t)$ is the increasing factor of the number of cars, whereas the $E_9(t)$ is the factor that expresses the growth of travel distances. These two factors are estimated by using the growth function. On the other hand, $E_{10}(t)$ is the energy-cost dependent factor in the transportation sector, for which a form similar to that of Equation (8) is assumed, with the energy cost $R_{Et}(t)$ and the elasticity η_5.

The last term of Equation (5), $E_{11}(t)$, is the factor representing the energy saving due to better energy use efficiency, that is the amount of energy required for the car to travel a unit length. This is also estimated by a growth function with a set of constants (a_{E11}, b_{E11}, c_{E11}).

As far as the energy costs, $R_{Ed}(t)$, $R_{Ei}(t)$ and $R_{Et}(t)$, are concerned, they are all assumed to follow Equation (15), which is common to all sub-sectors (k=d, i and t);

$$R_{Ek}(t) = R_{E0}(t)\left(1 + r_{Ek}(t)\right), \tag{15}$$

where $R_{E0}(t)$ is the base price of energy, and $r_{Ek}(t)$ is a policy factor which represents the effect of subsidies and taxation. In our model, the factor $r_{Ek}(t)$ is treated as an exogenously given policy factor.

Since the total energy consumption and the per capita energy consumption are calculated by using Equation (5), the per capita GNP can be derived by using one of the relations from Eqs.(1) to (3). In this case, it should be noted that the used is not Equation (5) itself, but the value of actual energy consumption without including the improving factors of energy use efficiency, $E_4(t)$, $E_7(t)$ and $E_{11}(t)$. The GNP and the per capita GNP are used as inputs in the sectors of water resources and agriculture.

3.2 Water Resources Sector

3.2.1 Water Demand

Water in Jordan is supposed to be used in three sub-sectors; agricultural (with the subscript a), domestic (d) and industry (i). The total water use and total water needs in Jordan at a time t, $W_{Ju}(t)$ and $W_{Jn}(t)$, respectively, are given by:

$$W_{Ju}(t) = W_a(t) + W_d(t) + W_i(t) \qquad (16)$$

$$= \varsigma_1 W_1(t) W_2(t) W_3(t) W_4(t) + \varsigma_2 W_5(t) W_6(t) W_7(t) p_1(t) + \varsigma_3 E_4(t) W_8(t), \qquad (17)$$

and

$$W_{Jn}(t) = W_{Ju}(t) \cdot W_9(t) W_{10}(t), \qquad (18)$$

where the coefficients ζ_1, ζ_2 and ζ_3 are constants that are to be determined by using the secular data of water's use in the past in the respective sub-sectors, $W_a(t)$, $W_d(t)$ and $W_i(t)$, by the method of least squares.

The quantity $W_1(t)$ in Eq.(17) is a factor representing the variation of irrigated area A(t), and it is given by:

$$W_1(t) = A(t)/A(0) = 1 + H(a_{W1}, b_{W1}, c_{W1} : t), \qquad (19)$$

where $H(a_{W1}, b_{W1}, c_{W1}{:}t)$ is the growth function. Irrigated area represents about 30% of the total agricultural land in Jordan in 2002 (Department of Statistics, 2001).

The factor $W_2(t)$ expresses the effect of adaptation for the water use in agriculture, which originates from the change in agricultural varieties and the method of farming, this change is due to the change of global climate, the transition of era, and the change of public consumption attitude with time. This also includes the effect of the change of irrigation methods from the so-called basin irrigation to more efficient methods. The $W_2(t)$ is supposed to be given by the growth function as:

$$W_2(t) = 1 + H(a_{W2}, b_{W2}, c_{W2} : t). \qquad (20)$$

$W_3(t)$ is a global temperature-dependent factor, representing the effect of increased water use with higher temperature,

$$W_3(t) = 1 + C_{W3} \cdot \Delta T(t), \qquad (21)$$

where C_{W3} is a constant (=0.2/degree) estimated from the data cited on McCarthy et al. (2001). On the other hand, the quantity $W_4(t)$ is water price- dependency factor given by

$$W_4(t) = \left(R_{wa}(t)/R_{wa}(0)\right)^{\lambda}, \qquad (22)$$

where $R_{Wa}(t)$ is the water price in the agricultural sector and $\lambda$is an elasticity whose value is determined by using the data from $W_4(t)$ and $R_{wa}(t)$ in the past.

The factor $W_5(t)$ in the second term of the right hand side of Eq.(17) corresponds to the change of water use in the domestic sector with the change of income, such as the increase of water used for house gardening. This is supposed to be given by a formula similar to Eq.(7);

$$W_5(t) = \left(G_c(t)/G_c(0)\right)^{\eta_1}. \qquad (23)$$

$W_6(t)$ is the temperature-dependent factor, similar to $W_3(t)$, but in the domestic sector;

$$W_6(t) = 1 + C_{W6} \cdot \Delta T(t), \qquad (24)$$

where C_{W6} is a constant (=0.1/degree) estimated from the data cited on McCarthy et al.(2001). Moreover, the $W_7(t)$ is the price-dependent factor for water use in the domestic sector, which is also given by the functional form similar to $W_4(t)$.

The quantity $E_4(t)$, which appeared in the energy part, is the factor of industrial productivity change. Its appearance in Eq.(17) is due to the assumption that the amount of water used in the industrial sub-sector is proportional to the industrial productivity. $W_8(t)$ is the water price-dependent factor, whose form is also similar to that of $W_4(t)$.

The $W_9(t)$ on the right hand side of Eq.(18) represents the progressive effect of technology on the efficient use of water by means of further reuse of once-used, and many-times-used waste water. Whereas, $W_{10}(t)$ the water loss prevention (better reach) factor due to water network rehabilitation against the so-called unaccounted-for water. In Eq.(18), we tacitly assumed that more reuse of once-used and many-times-used water and the improvement in water reach are sustained almost evenly throughout all sub-sectors. Both of those factors are assumed, for simplicity, to follow the growth function-like behavior, although they may decrease with time. In this case, their forms are, respectively, given by:

$$W_9(t) = 1/\left(1 + H(a_{W9}, b_{W9}, c_{W9} : t)\right) \tag{25}$$

and

$$W_{10}(t) = d_{W10} / \left(1 + H(a_{W10}, b_{W10}, c_{W10} : t)\right), \tag{26}$$

where d_{W10} is the reciprocal of the reaching rate (=0.65 : assumed) to the end user without any leak at the reference time. For this quantity, constants in the function are related to each other by the relation

$$d_{W10} = 1 + H(a_{W10}, b_{W10}, c_{W10} : \infty) \tag{27}$$

so that the improving factor $W_{10}(t)$ asymptotically approaches unity as improvement efforts continue.

The water prices $R_{Wn}(t)$, (n=a, d and i) appeared in $W_4(t)$, $W_7(t)$ and $W_8(t)$ are assumed also to be given by the similar form as that of the energy price, that is, Eq.(15);

$$R_{Wk}(t) = R_{W0}(t)\left(1 + r_{Wk}(t)\right), \tag{28}$$

where $R_{W0}(t)$ is the base price of water and $r_{Wk}(t)$ is a pricing policy factor which caters for both subsidy and taxation, along with the effect of the increased cost that is due to better purification of probably more deteriorated row water quality in the future, and the effect of the cost of developing new water resources. Calculation is made by giving the values of $r_{Wk}(t)$ as exogenous variables.

3.2.2 Water Supply

Water supply in Jordan $W_{Js}(t)$ at a time (t) is given by the following expression, assuming that water supply comes from both surface and ground water, $W_s(t)$ and $W_g(t)$;

$$W_{Js}(t) = W_s(t) + W_g(t) \tag{29}$$

$$= \varepsilon_1 W_{11}(t) W_{12}(t) W_{13}(t) + \varepsilon_2 W_{14}(t) W_{15}(t), \tag{30}$$

where the coefficients ε_1 and ε_2 are constants, which are determined by using the data of the amount of water supplied in the past. The quantity W_{11} ($\equiv 1+H(a_{W11}, b_{W11}, c_{W11}: t)$) is a factor that represents the effect of water supply by the development of new surface water resources such as new dams.

The $W_{12}(t)$ is the changing factor of precipitation due to the change of global climate, and is given by

$$W_{12}(t) = 1 + v_p(t), \tag{31}$$

where $v_p(t)$ is the rate of change of the precipitation. $W_{13}(t)$ is the factor that shows the effect of variation of the inflow of rainfall into river basins, which is caused by the change of vegetation and soil quality due to the global temperature change. It is assumed to be given by

$$W_{13}(t) = 1 + C_{W13} \cdot \Delta T_1(t), \tag{32}$$

where C_{W13} is a constant (=-0.15/degree; Martin, Dickinson and Yang,1999).

With regard to the second term on the right hand side of Eq.(30), the quantity $W_{14}(t)$($\equiv 1+H(a_{W14}, b_{W14}, c_{W14}: t)$) is the factor of increased water quantity pumped out from aquifer due to the development of new wells. The $W_{15}(t)$ is a factor representing the availability of usable underground water. The ground water in Jordan is constituted of two components. These are fossil water and circulating water. At the present time, fossil water fraction ω represents 12% of the total ground water used in Jordan (Department of Statistics, 2003a). The excess pumping-up leads to the depletion of the fossil water because of its non-renewable nature, while, on the other hand, the amount of circulating water available for use is influenced by the change of precipitation. Taking that into consideration, W_{15} is given by:

$$W_{15}(t) = \omega \cdot W_{16}(t) W_{17}(t) + (1 - \omega) W_{18}(t), \tag{33}$$

where the first and second terms on the right hand side correspond to the availability of fossil and circulation water, respectively.

The $W_{16}(t)$ ($\equiv 1+H(a_{W16}, b_{W16}, c_{W16}: t)$) in Eq.(33) is the depletion factor of the fossil water due to excess pump-out, whereas, $W_{17}(t)$($\equiv 1+H(a_{W17}, b_{W17}, c_{W17}: t)$) represents the refilling effect of the ground water in the case when the fossil aquifer is refilled by feeding the rain water into it through the refilling wells. The $W_{18}(t)$ is a factor to represent the effect of the variation of the amount of circulating water due to the varied precipitation caused by the global climate change, which is supposed to be given by:

$$W_{18}(t) = \max\left(0,\ 1 + g_p v_p(t)\right) \qquad (34)$$

where $v_p(t)$ is the rate of precipitation change and the g_p is a constant coefficient (=2.0 : assumed). It represents the propagation effect of the precipitation change on the amount of circulative ground water. For simplicity, it is assumed here that there exists no time lag between the change of precipitation and the change of the amount of circulation water.

Although the relation $W_{Jn}=W_{Js}$ holds at present, the amount of water to be developed in future Jordan, $W_{Jf}(t)$, is given by

$$W_{Jf}(t) = W_{Jn}(t) - W_{Js}(t). \qquad (35)$$

The deficit, as such, must be sought from resources other than the surface and ground waters. This deficit may be imported from neighboring countries or obtained through desalinization of sea water and the efficient management of rain water.

3.3 Agricultural Sector

The (i) types of agricultural products are introduced in our model. Although it is generalized as (i) types in the following formulation, only three types of products are considered in the concrete treatment and example calculation for simplicity. These are fruits (i=1), field crops (i=2) and vegetables (i=3).

3.3.1 Production of Agricultural Products

The amount of the product (i) at a given time t in region (k), $A_p^{ki}(t)$ is given by

$$A_P^{ki}(t) = \alpha_{ki}\Xi_k(t)\cdot\left(R_{AP}^{ki}(t)\right)^{\beta_{ki}} \prod_{j\neq i}\left(R_{Ap}^{ki}(t)\right)^{\beta_{kji}} \cdot A_1^{ki}(t)A_2^{ki}(t)A_3^{ki}(t)A_4^{ki}(t)A_5^{ki}(t), \qquad (36)$$

where α_{ki} is a constant, and β_{ki} and β_{kji} are elasticities. The values of these are determined by using the secular data from the past. $\Xi_k(t)$ is a normalization factor corresponding to the conservation of arable land area, $R_{Ap}^{ki}(t)$ is the producer price of the product (i) in the region (k). The above equation comes from the assumption that the higher becomes the producer's selling price of a product, the more it is preferable for the farmers to produce it. Reader is referred to Rosegrant, Meijer and Cline (2005) for the dependency of $A_p^{ki}(t)$ on the producer's selling prices.

The quantity $A_1^{ki}(t)(\equiv 1+H(a_{A1}^{ki},b_{A1}^{ki},c_{A1}^{ki} : t))$ is the factor of agricultural enhanced productivity, due to the introduction of new technologies such as:

- better selection of fertilizer,
- choosing production times most appropriate for the global change of climate,
- the adjustment of production cycles,
- the improvement brought about by genetic engineering, and
- more mechanization.

On the other hand, the $A_2^{ki}(t)(\equiv 1+H(a_{A2}^{ki},b_{A2}^{ki},c_{A2}^{ki}: t))$ is the factor of arable area increase by reclaiming new land. The quantity $A_3^{ki}(t)$ represents the irrigation factor. Here we simply assume that the agricultural productivity varies in a manner of growth function in terms of the water available for irrigation $W_a(t)$. In this case it is given by

$$A_3^{ki}(t) = 1 + H(a_{A3}^{ki}, b_{A3}^{ki}, c_{A3}^{ki} : w(t)). \qquad (37)$$

Here, $w(t)\equiv(W_a(t)-W_a(0))/W_a(0)$ for Jordan, and $w(t)\equiv(\rho_k(t)-\rho_k(0))/\rho_k(0)$ for Arab League (k=2) and the other region (k=3), where $W_a(t)$ is the quantity derived in the water resources sector by Eqs.(16) and (17), and ρ_k is the annual precipitation in k.

The quantity $A_4^{ki}(t)$ is the enhanced productivity factor due to increased atmospheric CO_2, whereas the $A_5^{ki}(t)$ corresponds to the similar factor, but due to the increased temperature. They are, respectively given by

$$A_4^{ki}(t) = 1 + C_{A4}^{ki}\cdot\Delta CO_2(t) \qquad (38)$$

and

$$A_5^{ki}(t) = 1 + C_{A5}^{ki}\cdot\Delta T_k(t), \qquad (39)$$

where C_{A4}^{ki} and C_{A5}^{ki} are constants ($c_{A4}^1=c_{A4}^3=0.1$, $c_{A4}^2=0.2$, $c_{A5}^1=c_{A5}^2=c_{A5}^3=0.1$: estimated from the data cited in McCarthy et al. (2001)), $\Delta CO_2(t)=(C_{CO2}(t)-C_{CO2}(0))/C_{CO2}(0)$, and $\Delta T_k(t)=T_k(t)-T_k(0)$, $C_{CO2}(t)$ being the atmospheric concentration of CO_2, and $T_k(t)$ is the atmospheric temperature in region k.

Eq.(36) implies that the relative production of the product i to that of the other products varies with the change of prices and the other factors. This means that the relative area of the arable land for the product i, $s_{ki}(t)$, changes with time. Even if it varies, the variability of each $s_{ki}(t)$ can not be unlimited, but rather restricted to the total cultivated area at a reference time $S_k(0)$ by the following relation:

$$S_k(0) = \sum_i s_{ki}(t) / A_2^{ki}(t) \tag{40}$$

Setting the productivity of the product (i) per unit area of land as $\sigma_{ki}(t)(=\sigma_{ki}(0)A_1^{ki}(t)A_3^{ki}(t)A_4^{ki}(t)A_5^{ki}(t))$, Eq.(40) can be rewritten by using Eq.(36) as:

$$S_k(0) = \sum_i A_p^{ki}(t) \Big/ \left(\sigma_{ki}(t) A_2^{ki}(t)\right) \tag{41}$$

$$= \Xi_k(t) \sum_i \left[\alpha_{ki} \left\{R_{Ap}^{ki}(t)\right\}^{\beta_{ki}} \prod_{j \neq i} \left\{R_{Ap}^{kj}(t)\right\}^{\beta_{kji}} \Big/ \sigma_{ki}(0) \right]. \tag{42}$$

Hence, the normalization factor $\Xi_k(t)$ is given by

$$\Xi_k(t) = S_k(0) \Big/ \sum_i \left[\alpha_{ki} \left\{R_{Ap}^{ki}(t)\right\}^{\beta_{ki}} \prod_{j \neq i} \left\{R_{Ap}^{kj}(t)\right\}^{\beta_{kji}} \Big/ \sigma_{ki}(0) \right], \tag{43}$$

where $S_k(0)$ and $\sigma_{ki}(0)$ are to be given as constants (Department of Statistics, 2004).

3.3.2 Consumption of Agricultural Products

The consumption of the product (i) in region (k) at time (t), $A_C^{ki}(t)$, is given by:

$$A_C^{ki}(t) = \gamma_{ki} \left(R_{Ac}^{ki}(t)\right)^{\delta_{ki}} \cdot \prod_{j \neq i} \left(R_{Ac}^{kj}(t)\right)^{\delta_{kji}} \cdot A_6^{ki}(t) A_7^{ki}(t), \tag{44}$$

where $R_{Ac}^{ki}(t)$ is the consumer price of the product (i) in region (k), and γ_{ki} is a constant coefficient, and δ_{ki} and δ_{kji} are elasticities. The γ_{ki} is to be determined by using the secular data in the past, whereas δ_{ki} is set in the example calculation as: $\delta_{11}=\delta_{13}=-0.486$, $\delta_{12}=-0.385$, $\delta_{21}=\delta_{23}=-0.445$, $\delta_{22}=-0.332$, $\delta_{31}=\delta_{33}=-0.225$, and $\delta_{32}=-0.129$ (USDA, 2005), and $\delta_{kji}=0$ for all kji.

The factor $A_6^{ki}(t)$ $(\equiv p_k(t)/p_k(0))$ is the factor of the increase in number of consumer of the product (i), p_k being the population in the region (k). Whereas, $A_7^{ki}(t)$ is the income-dependent factor which originates from the fact that the consumption increases with the increase of income. $A_7^{ki}(t)$ is given by:

$$A_7^{ki}(t) = \left(G_{ck}(t) / G_{ck}(0)\right)^{\varepsilon_{kki}}, \tag{45}$$

where $G_{ck}(t)$ is the per capita GNP in region (k), and ε_{ki} is the elasticity which is set in what follows as $\varepsilon_{11}=\varepsilon_{13}=0.601$, $\varepsilon_{12}=0.477$, $\varepsilon_{21}=\varepsilon_{23}=0.552$, $\varepsilon_{22}=0.411$, $\varepsilon_{31}=\varepsilon_{33}=0.278$ and $\varepsilon_{32}=0.159$ (USDA,2005).

The producer and consumer selling prices, $R_{Ap}^{ki}(t)$ and $R_{Ac}^{ki}(t)$, are respectively given by:

$$R_{Ap}^{ki}(t) = R_i^0(t)\left(1 - m_p^{ki}(t)\right)\left(1 + e_p^{ki}(t)\right) \tag{46}$$

and

$$R_{Ac}^{ki}(t) = R_i^0(t)\left(1 + m_c^{ki}(t)\right)\left(1 + e_c^{ki}(t)\right), \tag{47}$$

where $R_i^0(t)$ is the world price of the product (i), $m_p^{ki}(t)$ is a factor for the marketing margin, $e_p^{ki}(t)$ is the factor corresponding to the agricultural subsidies, and $m_c^{ki}(t)$ and $e_c^{ki}(t)$ are the factors corresponding to the consumer side, which include the effects of subsidies, taxes, and custom duties. These factors are treated as exogenously given policy factors in our model.

The required amount of product (i) to be imported into or to be exported from the region (k), $A_I^{ki}(t)$, is given by:

$$A_I^{ki}(t) = A_C^{ki}(t) - A_P^{ki}(t). \tag{48}$$

From the conservation rule of the amount of (i) over all countries, the following condition must be held in every year for each (i) product when the stock of product (i) is negligible compared to $A_C^{ki}(t)$ and $A_P^{ki}(t)$;

$$\sum_k A_I^{ki}(t) = 0. \tag{49}$$

The world price of a certain product $R_i^0(t)$ must be determined in our model so that the above non-linear simultaneous equations Eq.(49) remains valid at any given time (t).

4. CALCULATIONAL METHOD

The temperature increase $\Delta T_1(t)$ and the precipitation increase $\Delta\rho_1(t)$ $(\equiv\rho_1(t)-\rho_1(0))$, also, they gradually change with time, following the gradual increase of CO_2 concentration, to asymptotically approach their respective final values ΔT_1^∞ and $\Delta\rho_1^\infty$. In our model, the temperature and the precipitation, along with the concentration of CO_2, are assumed to linearly vary up to the year 2050 when they stabilize at their respective maxima ,ΔT_1^∞, $\Delta\rho_r^\infty$ and $\Delta CO_2(\infty)$ $(\equiv(CO_2(\infty)-CO_2(0))/CO_2(0))$. Setting these quantities as $X(t)$ and reference time as t_0, then, they are given by:

$$X(t) = \min\left[\left(X^{\infty} - X(t_0)\right)(t - t_0)/(2050 - t_0),\ X^{\infty}\right] \quad (50)$$

For simplicity in this case, no time lag is assumed between the change of those quantities.

Since the future forecast of meteorological quantities such as temperature and precipitation in a certain local region vary from a certain GCM to another GCM, there exists considerable ambiguity for the future values of those quantities. Therefore, in order to estimate the effect and assess the influence of the global climate change on a certain local region, like Jordan, it is not necessarily a right way to use only one GCM, or to simply average the results from several GCMs. It should be noted here that those meteorological quantities can barely be said to distribute within a certain ranges of the respective values according to some probabilistic function. This is due to the present level of precision of GCM calculations. Such a situation is taken into account in our calculation, so that the probabilities for the final values of ΔT_1^{∞} and $\Delta\rho_1^{\infty}$, $\varphi(\Delta T_1^{\infty})$ and $\varphi(\Delta\rho_1^{\infty})$, are given by the normal distributions around the respective central values ΔT_1^{0} and $\Delta\rho_r^{0}$. That is

$$\phi(\Delta T_1^{\infty}) = \Phi(\Delta T_1^{\infty} : \Delta T_1^{0}, \sigma_{T1}) \quad (51)$$

and

$$\phi(\Delta\rho_1^{\infty}) = \Phi(\Delta\rho_1^{\infty} : \Delta\rho_1^{0}, \sigma_{\rho1}). \quad (52)$$

Here, σ_{T1} and $\sigma_{\rho1}$ are standard deviations, and the function $\Phi(x{:}X,\sigma)$ is defined by

$$\phi(x : X, \sigma) = \frac{1}{\sqrt{2\pi\sigma}} \exp\left[-\frac{1}{2}\{(x - X)/\sigma\}^2\right] \quad (53)$$

The values such as ΔT_1^{0}=3.0degree, $\Delta\rho_1^{0}$=-85mm/y, and $\sigma_{T1}/\Delta T_1^{0} = \sigma_{\rho1}/\Delta\rho_1^{0} = 0.3$, will be applied in what follows for the case of the increase of CO_2 concentration by the same amount as that of the present, that is$\Delta CO_2(\infty)=1$.

The model assumes the similar type of ambiguity for the extents of growth of population in the future Jordan, $p_1(t)$, and it is assumed as:

$$p_1(t) = p_1(0)\left[1 + c_{p1}^{\infty}\left\{\begin{matrix}\exp(b_{p1}) - \\ \exp(-a_{p1}t + b_{p1})\end{matrix}\right\} \Big/ \left\{\begin{matrix}\left(1 + \exp(b_{p1})\right) \\ \left(1 + \exp(-a_{p1}t + b_{p1})\right)\end{matrix}\right\}\right] \quad (54)$$

and

$$\phi(c_{p1}^{\infty}) = \Phi(c_{p1}^{\infty} : c_{p1}, \sigma_{cp1}), \quad (55)$$

where the right hand side of Eq.(54) is the growth function and a_{p1}, b_{p1} and c_{p1} are constants to be determined by using the secular data from the past. Whereas σ_{cp1} is assumed as$\sigma_{cp1} = 0.3c_{p1}$.

In the example calculation, the values of the three variables ΔT_1^{∞}, $\Delta\rho_1^{\infty}$, c_{p1}^{∞} are randomly determined according to the above probabilistic functions, then the estimation of the various quantities for future Jordan are made for every year from 2000 to 2100. Repeating this process many times, for instance, 1000 times, and taking ensemble means of the respective quantities from these 1000 trials, final values of the quantities are obtained. The "standard values" in the following calculation, which are derived for comparison with those ensemble means, are the values corresponding to the results with a set of values (ΔT^{∞}, $\Delta\rho_1^{\infty}$, c_p^{∞})=(ΔT^{0}, $\Delta\rho_1^{0}$, c_{p1}) under condition of no global climate change.

The model, as already described, was developed aiming at investigating the extent of future influence of various Jordanian policies of energy, water and agriculture on the Jordanian society, economics and etc, under the condition of global climate change. Here, the policies are restricted to the technical policies with regard to;

(1) the control of energy price by the government,
(2) the introduction and promotion of various measures and technologies to face the water problem. These include the improvement technology of reusing used water, the improvement of the reaching rate of supplied water, the restrictions on the use of ground water, the promotion of the development of ground water, the promotion of setting refilling wells as a mitigation of fossil water exhaustion, the promotion of new and newly-typed dam construction, and the promotion of the desalinization of sea water,
(3) the advancement in the improvement of agricultural productivity,
(4) the advancement in the reduction of irrigation water by introducing positive measures of adaptation,
(5) the control of water price by the government, and
(6) the control of the prices of agricultural products by the government.

The model calculates the extent of the variation of the results when the values of the constants and the coefficients related to those policies are changed within respective uncertainty ranges.

Table (1): Values of constants used in the example calculation.

---

constants relating to the water resources sector

$a_{W9}=a_{W10}=a_{W12}=a_{W15}=a_{W17}=0.05,\ a_{W18}=0.02,$

$b_{W9}=b_{W12}=b_{W15}=b_{W18}=2.0,\ b_{W10}=b_{W17}=1.0,$

$c_{W9}=c_{W12}=c_{W15}=c_{W17}=c_{W18}=1.0,\ c_{W10}=0.5$

constants relating to the agricultural sector for all k and i

$a_{A1}{}^{ki}=0.02,\ b_{A1}{}^{ki}=1.0,\ c_{A1}{}^{ki}=1.0,\ a_{A3}{}^{ki}=1.0,\ b_{A3}{}^{ki}=c_{A3}{}^{ki}=0.5$

constants relating to prices in fils/kg

$R_{Ed}(t)= R_{Ei}(t)= R_{Et}(t)= R_{Wa}(t)= R_{Wd}(t)= R_{Wi}(t)=1.0,$

$R_1{}^0(0)=205,\ R_2{}^0(0)=89,\ R_3{}^0(0)=92,$

$R_p{}^{11}(0)=185,\ R_p{}^{12}(0)=67,\ R_p{}^{13}(0)=78,\ R_c{}^{11}(0)=224,$

$R_c{}^{12}(0)=116,\ R_c{}^{13}(0)=107,$

$R_p{}^{21}(0)=167,\ R_p{}^{22}(0)=60,\ R_p{}^{23}(0)=70,$

$R_c{}^{21}(0)=202,\ R_c{}^{22}(0)=100,\ R_c{}^{23}(0)=96,$

$R_p{}^{31}(0)=204,\ R_p{}^{32}(0)=74,\ R_p{}^{33}(0)=86,$

$R_c{}^{31}(0)=246,\ R_c{}^{32}(0)=122,\ R_c{}^{33}(0)=118,$

$m_p{}^{ki}(t)$, $m_c{}^{ki}(t)$, $e_p{}^{ki}(t)$, and $e_c{}^{ki}(t)$ are all constant throughout t $(0, \infty]$

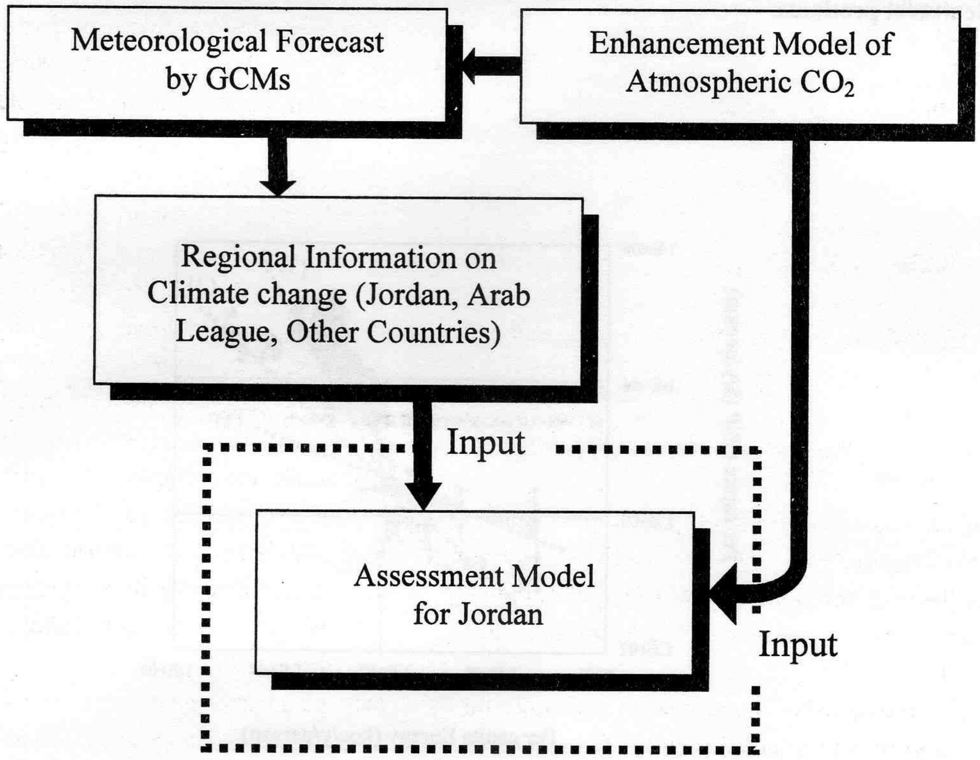

Fig.1 T.Ohnishi and W.R.Tyfour (I)

Fig.1. Position of our model, which is enclosed by dotted lines, in the models regarding global climate change. Information flow is indicated by arrows.

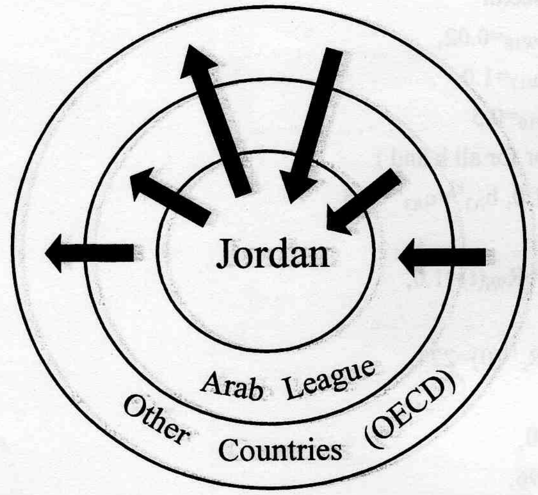

Fig.2 T.Ohnishi and W.R.Tyfour (I)

Fig.2. Relation between three regions from which the world is consisted. Arrows indicate the exchange of agricultural products.

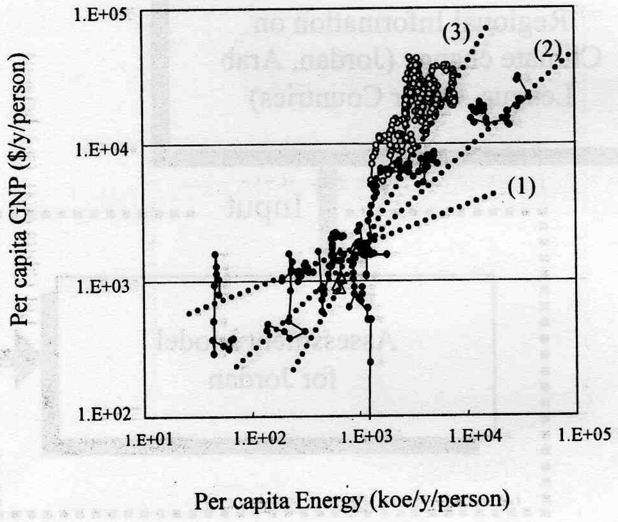

Fig. 3. T.Ohnishi and W.R. Tyfour (I)

Fig.3. Relation between the per capita energy use and the per capita GNP for Arabic countries (with solid circles) and OECD countries (with open circles), each of those secular data being connected by lines with every country. The Jordanian data points are indicated by open triangles. The recurrent lines (1), (2) and (3) correspond respectively to Eqs.(1), (2) and (3) in the text.

Fig.4 T.Ohnishi and W.R.Tyfour (I)

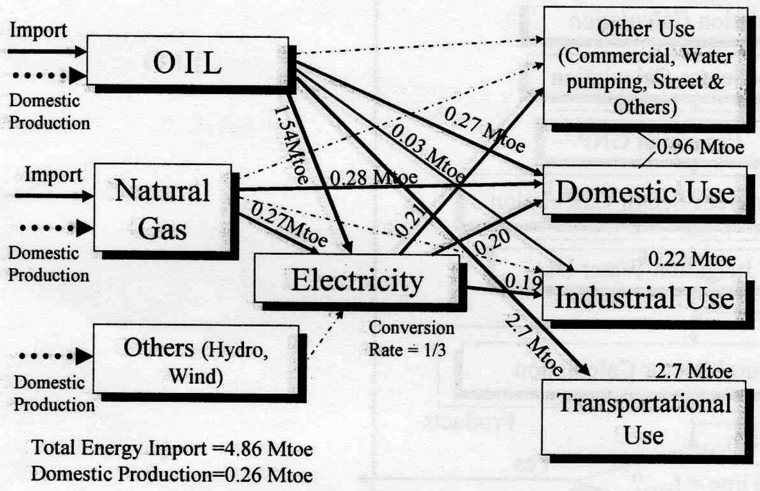

Fig.4. Energy flow in Jordan in the year 2000.

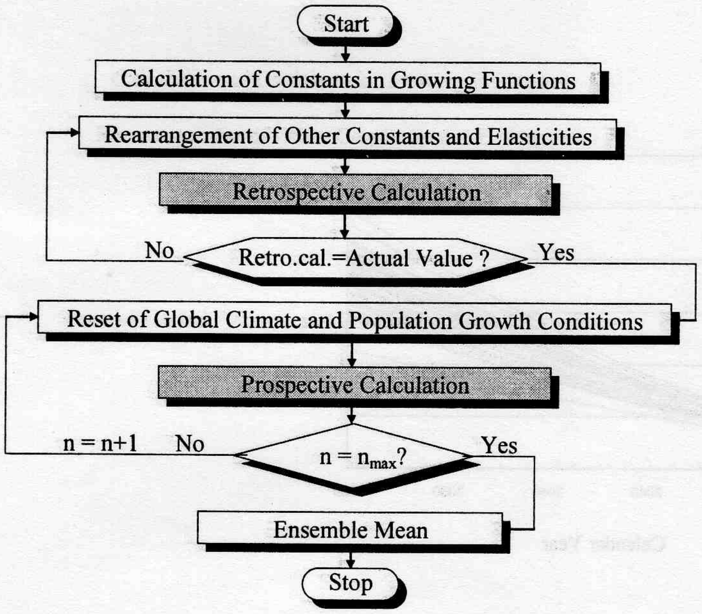

Fig.5. T.Ohnishi and W.R.Tyfour (I)

Fig.5. Flow chart of general calculation. The part of retro- and prospective calculation is detailed in Fig.6.

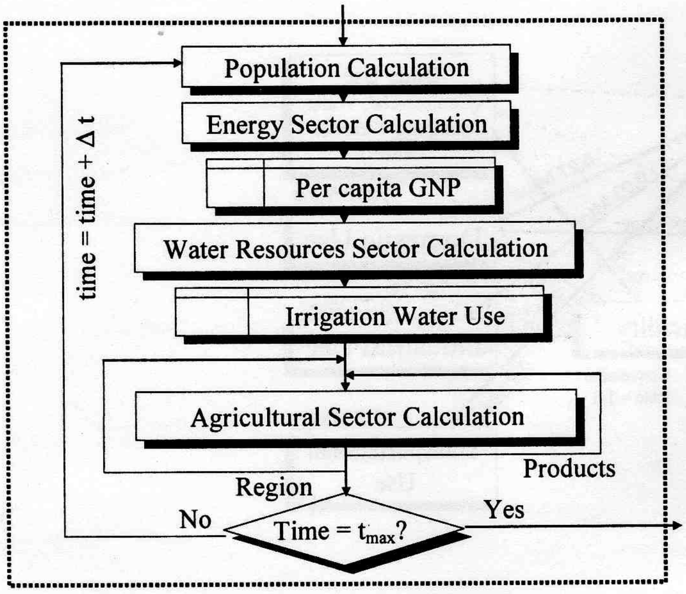

Fig.6 T.Ohnishi and W.R.Tyfour (I)

Fig.6. Flow chart of calculation in the retro- and prospective directions in time. The per capita GNP and the irrigation water use are the output information to be used in the next step of calculation.

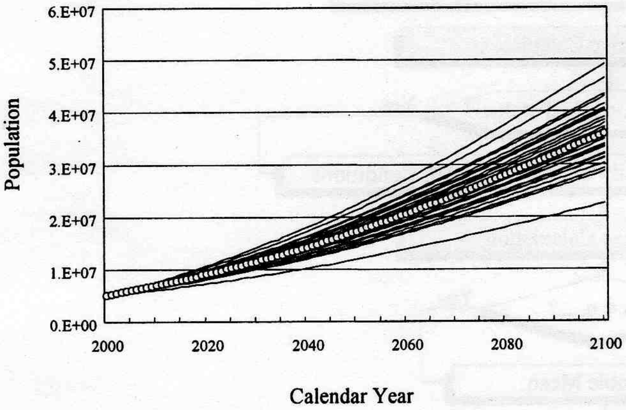

Fig.7 T.Ohnishi and .R.Tyfour (I)

Fig.7. Feature of population growth with time. Solid lines represent the results of 30 independent trials, and the dotted curve shows the ensemble mean, which does not depend on the scenario.

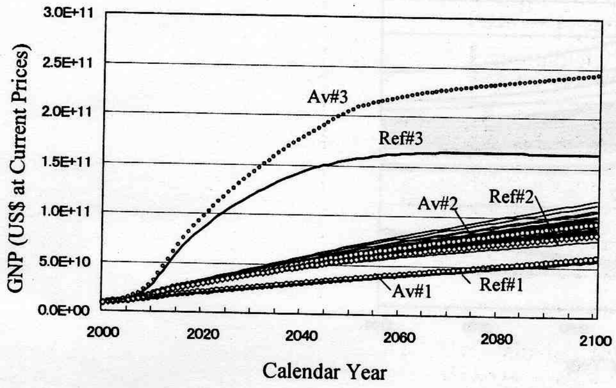

Fig.8 T.Ohnishi and W.R.Tyfour (I)

Fig.8. Behavior of GNP in US$ at current prices with time. Solid lines represent the results of 30 independent trials for the case of scenario 2. Av#n and Ref#n respectively indicate the ensemble mean and the reference value, both for the scenario n.

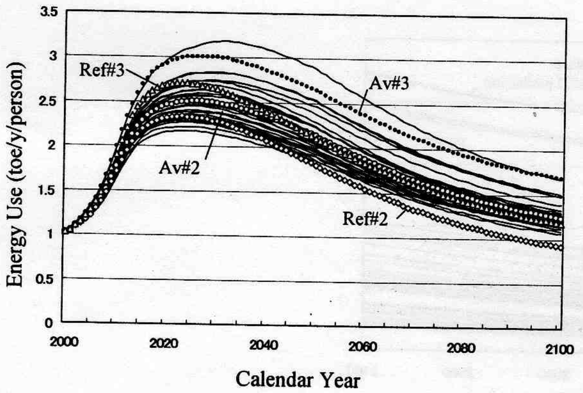

Fig.9 T.Ohnishi and W.R.Tyfour (I)

Fig.9. Time evolution of the per capita energy use for the case of scenario 2. Solid lines represent the results of 30 independent trials, and Av#2 and Ref#2 respectively indicate the ensemble mean and the reference value.

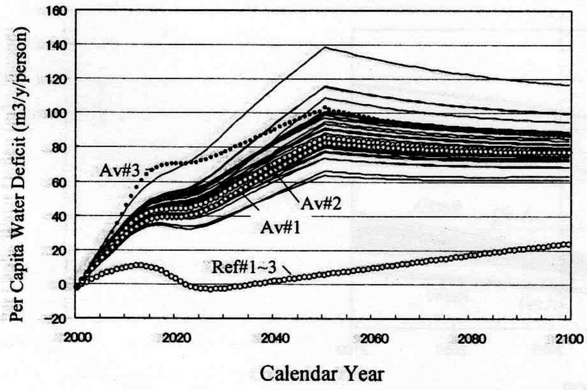

Fig.10 T.Ohnishi and W.R.Tyfour (I)

Fig.10. Time evolution of the per capita water deficit. Solid lines represent the results of 30 independent trials for the case of scenario 2. Av#n indicates the ensemble mean for the scenario n, and Ref#1-3 the reference value which is not dependent on any scenario.

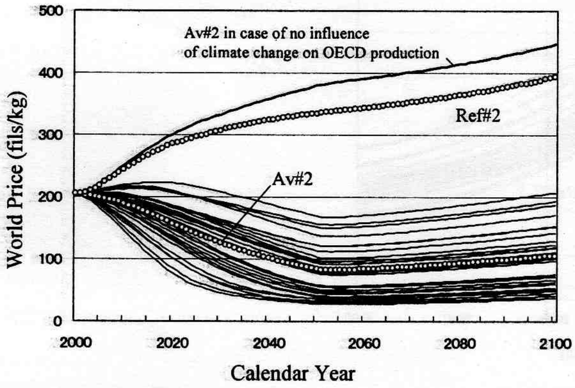

Fig.11 T.Ohnishi and W.R.Tyfour (I)

Fig.11. Variation of world price of fruits with time for the case of scenario 2. Solid lines represent the results of 30 independent trials. Av#2 represents the ensemble mean, "Av#2 without influence" the result without the condition of any influence of climate change in OECD countries, and Ref is of the value without the influence of that change all over the world.

Since, in our model, many statistical quantities in the future are estimated by analyzing the past behavioral feature of those quantities. As already described, a large amount of information on the secular variation of those quantities in each region and for each agricultural product is necessarily required. Data bases such as Department of Statistics (2003a, 2003b, 2004, every year), USDA(2005), United Nations (every year) and FAO (2005) are used to retrieve the required data. Estimated values are used as default values when data are unavailable. The flow charts of the computer program are shown in Figures (5) and (6).

5. EXAMPLE CALCULATION

Numerical values of some constants and elasticities were already given in section (3). Except for those quantities, the values given in Table (1) are adopted in the example calculations. Although the results shown are for Jordan under the condition of Eq.(2), some results with other conditions are also shown for comparison. 1000 trials of calculation were carried out with different values of quantities of global climate forecast and different population growth rates. The results of 30 trials are also shown as "spaghetti curves" on each figure, each of which is selected from every 33 trials, together with the ensemble mean of those 1000 trials, to indicate the range of uncertainty. The "reference value" in each figure is the one without any influence of climate change. The scenarios 1~3 respectively correspond to the evolution along the passes of Eqs.(1) ~ (3).

Figure (7) shows the feature of population growth. The reference value in this case is almost the same as the ensemble mean. As already stated in section (3), population forecast was made by extrapolating the past trend with the use of a growth function. For the period of 100 years (2000-2100), Jordan population seems to exponentially increase to about 7 times the population of the year 2000. This corresponds to a population growth rate of about 2% per year.

Figure (8) shows the variation of GNP at current prices. In the cases of scenarios (1) and (2), it gradually grows, almost linearly, with time up to the year 2100 to respectively become about 11 and 7 times the initial value of 8.5×10^9 US$ in 2000. As these growths are almost the same as or only slightly greater than the multiplicity of the population, the per capita GNP can hardly increase in these cases. On the other hand, in the case of scenario (3), the GNP grows remarkably in the first half of this century to asymptotically approach 2.4×10^{11} US$ in the case of climate change. In this case, the per capita GNP becomes maximum, about 1.3×10^4 US$/capita, in the year around 2030, and then gradually decreases due to the increase of population to reach 7.0×10^3 US$/person in 2100. It should be noted here that such a behavior of decreased per capita GNP corresponds to the case where no countermeasures are taken by the government, despite the fall of the value. It is, therefore, very important to decide on what is the appropriate policy to be followed in Jordan to sustain a continuous GNP growth.

Figure (9) shows the per capita energy use. For the case of ensemble mean, maxima of about 2.5 toe/year/capita for the scenario (2), and 3.3 toe/year/capita for the scenario (3) appear in the per capita energy use in the first half of this century. For all scenarios, the per capita energy use under the climate change is higher by about 20% than that of the reference value. This is mainly due to the increase of energy use in the domestic sector caused by the temperature increase. In the case of the scenario (2), the per capita energy use in 2100 decreases to about the same value as in 2000. In spite of this decrease, the burden to be born by the Jordanian government for the import of energy will never decrease throughout this century because of the high rate of population growth. In the case of the scenario (3), however, this burden, that is the ratio of the cost required for the import of energy to GNP, is reduced to about half that of scenarios (1) and (2).

Figure (10) shows the per capita water deficit. The deficit in the year 2000 is substantially null. Although the deficit in the case of no climate change is always less than 20 m^3/year/person, it becomes remarkably high in the case of climate change, regardless of scenario. The transition on the curve corresponding to the year around 2050 originates from the hypothesis that the meteorological variables for the case of climate change remains constant after 2050, as given by Eq.(50). Since the per capita amount of water fed in 2000 is about 140 m^3/year/person (Department of Statistics, 2003a), it is about half of this amount, in the case of climate change, that is further needed for each person throughout the second half of this century. The amount needed all over Jordan becomes tremendous when we take the population growth into account. It is, therefore, so urgent to investigate whether there exist any thorough solutions to such a severe water shortage.

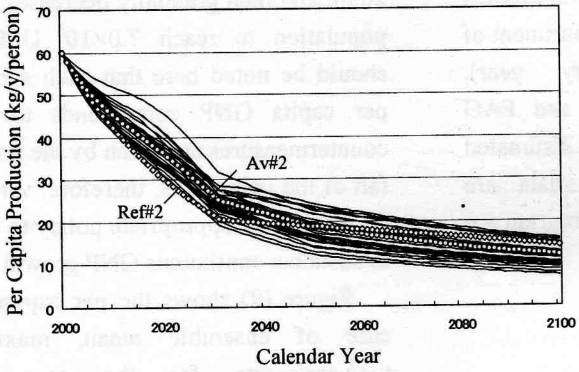

Fig.12 T.Ohnishi and W.R.Tyfour (I)

Fig.12. Behavior of the per capita production of fruits with time for the case of scenario 2. Solid lines represent the results of 30 independent trials, and Av#2 and Ref#2 respectively indicate the ensemble mean and the reference value.

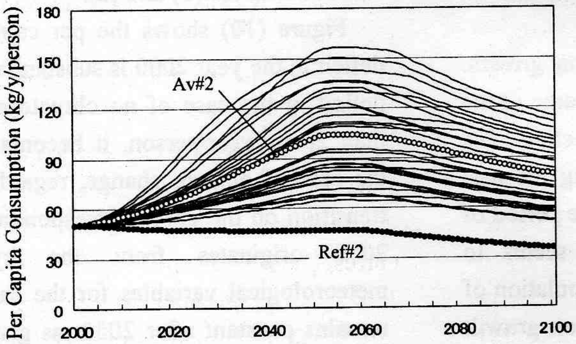

Fig.13 T.Ohnishi and W.R.Tyfour (I)

Fig.13. Behavior of the per capita consumption of fruits with time for the case of scenario 2. Solid lines represent the results of 30 independent trials, and Av#2 and Ref#2 respectively indicate the ensemble mean and the reference value.

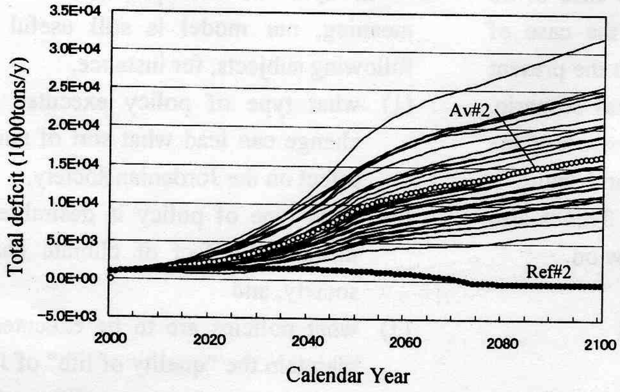

Fig.14 T.Ohnishi and W.R.Tyfour (I)

Fig.14. Time evolution of the total deficit of agricultural products. Solid lines represent the results of 30 independent trials for the case of scenario 2. Av#n and Ref#n respectively indicate the ensemble mean and the reference value, both for the scenario n.

Agricultural results are shown hereinafter, taking the case i=1, that is fruits, as an example. Figure (11) shows the time variation of the world price of fruits. The world price is strongly depending on the supply and demand in the region where the product is largely produced or consumed. In our mode, therefore, it is determined by those trend in OECD countries. Since, in the case of climate change, both the temperature and precipitation, along with the CO_2 concentration, increase on an average in the middle latitude regions where many OECD countries situate, and since the increase of those quantities generally lead the desirable effects on vegetation, the agricultural productivity in OECD increases. This leads to a decrease in the world price of the product. In the case of no climate change, on the other hand, the world price gradually increases because of low supply due to the un-expandable arable land despite the expansion of population. This price in 2100, therefore, reaches 2.2 times the present price in the case of the scenario (2). Such rise and fall of world price is one of the important factors which determine the public attitude of supply and demand of agricultural products in Jordan.

Figure (12) shows the per capita productivity of fruits. The decrease of this quantity with time is owed firstly to the trend of gradual decrease of the farm area for fruits with time in Jordan (and hence the relative area for the other products such as crops and vegetables, contrary to fruits, seems to increase with time according to the secular data in the past (Department of Statistics, 2004)). The other reason for that decrease is the population growth in Jordan.

Figure (13), on the other hand, gives the per capita annual consumption of fruits. The consumption increases mainly because of the low price of fruits in the case of climate change. The per capita deficit of fruits is given by the difference of the values in figures (12) and (13). This corresponds to the per capita amount of fruits that the Jordanian government must import from near Arab league countries and/or OECD countries. This quantity grows to more than two times the present value in the year around 2050, before it starts to slightly decrease with time. Since the per capita consumption of fruits in Jordan in 2000 was 49.4 kg/year/person (Department of Statistics, 2004), a large amount of fruits must be imported in the future in the case of climate change, regardless of the evolutional scenario.

Figure (14) shows the total amount of deficit of agricultural products, that is the difference of the total amount of import and the total amount of export of all products. Although the value of such a quantity is almost the same in the future as the present value of 8.84×10^5 tons (Department of Statistics, 2004) in the case of no climate change, it increases with time in the case of climate change to become a value of 20 times the present amount in 2100 regardless of the evolutional scenario. Such a situation indicates that the growing import of the agricultural products will become more and more a serious problem with time in future Jordan. This is also the significant subject to be resolved from now on.

6. CONCLUDING REMARKS

Since various factors regarding policy making are integrated into our model, we can estimate the extent of the effect of policy execution on the future Jordanian society by changing the value of the variable corresponding to the respective policy. The model, however, cannot be so precise as to simulate future Jordan with sufficient accuracy, and is forced to say that it is for use of qualitative prediction rather than of quantitative estimation. Such a characteristic is necessarily accompanied with any types of global model so that our model is to be comprehended as to offer one methodology to estimate and forecast the future direction of Jordanian society. Concrete policy making is to be made by incorporating and comparing with other results obtained by using other methodologies.

In spite of the qualitative nature of the above meaning, our model is still useful to investigate the following subjects, for instance,

1. what type of policy executed under the climate change can lead what sort of and to what extent of effect on the Jordanian society,
2. what type of policy is desirable to make least the influential effect of climate change on Jordanian society, and
3. what policies are to be executed at what times to maintain the "quality of life" of Jordanian maximum at all times under the condition of climate change.

Moreover, with regard to the improvement of our model, the followings are to be considered hereafter:

1. extension of the number of regions into which the world is divided and the number of agricultural products, both to the number greater than three, which is the one used in this model,
2. integration of the international trade of CO_2 emission right, and
3. collection and rearrangement of more reliable secular data of various statistical quantities in Jordan.

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