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The Impact of Agricultural Policies on the Sustainability of Resource Use - A Case Study from Yemen

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Abstract
Water supplies in Yemen are depleted in an unsustainable manner because of increasing demand from a fast growing population and an expanding agricultural sector. Political efforts should ensure a more efficient allocation of the scarce resource among uses and users, but little information is available about the likely effects of policy changes on farmers' attitudes and practices. This paper shows how an economically based agriculture sector model was combined with a hydrological model to serve as an analytical and planning instrument. The model is based on micro-level data collected during the 1997/98 agricultural season in the delta of Wadi Tuban, located near Aden (13°N. 45°E.) and was established using the GAMS-Software package (General Algebraic Modelling System).

Keywords: Yemen, water resource management, sustainability, policy analysis, sector model

Introduction

The findings presented in this poster/paper result from research conducted between 1996 and 1999 on behalf of the IDAS project. ”Innovation Development in the Agricultural Sector” is a joint German-Yemen project, financed by BMZ (Ministerium für wirtschaftliche Zusammenarbeit und Entwicklung) and implemented by GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit). IDAS' project purpose is that ”Farmers in the project area increasingly solve their problems in the field of sustainable agriculture and productivity independently, and are supported by external institutions on request” (GTZ, 1996). In this context a qualitative and quantitative assessment of chances and constraints for promoting the target variables ”sustainability” and ”productivity” should be given. Actually existing and potentially applicable policy instruments should be analysed with respect to their influence on the target variables via farmers' behaviour. Located within the IDAS project's area of activity, Wadi Tuban Delta was chosen as survey region (see figure 1). The delta, which comprises some 30,000 hectares gross agricultural area, is located north of Aden at approximately 13°N and 45°E. Aden is the second largest town in Yemen with some 450,000 inhabitants.
(1998 exchange rate: 100 YR = 0.8 US$)

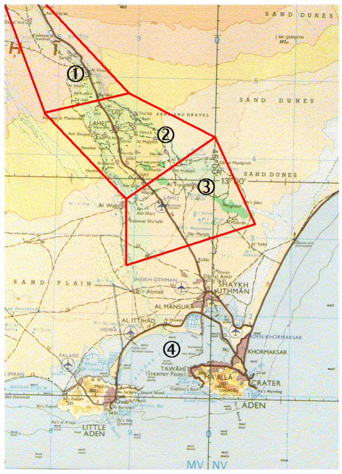


Figure 1. Location of project region (left) and survey region (right) showing the three model regions represented by their respective villages ”AlChodad” ①, ”AlMajhefah” ② and ”AlFeyoush” ③ as well as the urban consumption centre ”Aden” ④.

Problem Identification and Problem Analysis

The scarcity of water resources is a serious obstacle to development in many parts of the world. Since 1950 the world demand for water has increased by the factor four while world population ”just” doubled (BMZ, 1997). Utilisation of water in irrigated agriculture has played a major role in this development. In Yemen, where the population grows at an annual rate of 3.8 %, around 92 % of water use can be attributed to agriculture while private consumption of water is as little as 46 litres per person and day. (WORLD BANK, 1998). As the quantity of water used nowadays exceeds the amount of annually renewed water, Yemen relies on the depletion of groundwater reserves. This has already resulted in a steady decrease of groundwater levels in many of the country’s aquifers (GUN ET AL, 1995). Coastal aquifers are further put at risk as they face the danger of sea water intrusion.

Although in the last decade oil exports gained a lot of importance within Yemen’s economy, the agricultural sector as well achieved remarkable growth. Between 1990 and 1996 value of agricultural production at constant prices increased at an average annual rate of 4.4 %. Growth was achieved by structural change and mechanic-technical progress, predominantly in the form of diesel powered engines for pumping groundwater.

Agriculture in the survey region is fully dependent on irrigation, as annual average precipitation is just 40 mm while potential evapotranspiration is 3000 mm (VILLWOCK, 1991). Reasons behind the observed degree of over-utilisation of groundwater resources are:

(a) The climatic conditions

(b) The demographic trend

(c) The political and economic conditions in which agriculture is acting. In this field unsustainable use of groundwater has been particularly supported by:

i) policies aimed at meeting increased water demand by supply management options (e.g. the provision of more irrigation infrastructure)

ii) policies aimed at providing indirect subsidies for irrigation water (e.g. cheap energy for pumping groundwater)

Factors (a) and (b) are hard to be influenced in the short-term, so this study focuses on the political framework (c). The following individual phenomena, which have their roots in this framework and –altogether- cause the water crisis in Yemen, can be identified:

Technology: The irrigation infrastructure provided by the public enhance utilisation of flood water and accordingly reduce groundwater recharge by infiltrating surface water.

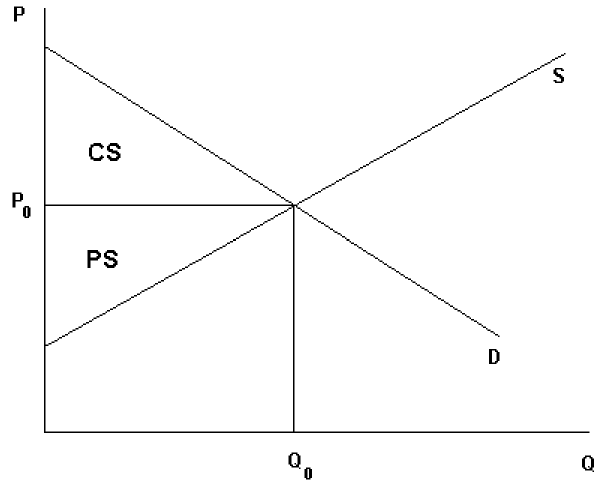
Inefficient water conveyance technology causes high losses through infiltration and evaporation from canals.
Inappropriate water application methods (irrigation during times of high radiation, pool irrigation) increase absolute agricultural water demand.
Water saving irrigation technologies are hardly applied because of limited knowledge, availability and/or rentability.
Subsidies: Groundwater irrigation is indirectly subsidised through cheap diesel and low interest credit for pumping equipment. As a result water has a high relative factor efficiency as compared with land and/or labour.
Trade policies: Attractiveness of growing fruits and vegetables is enhanced by effective tariff and non-tariff barriers to imports. At the same time local cereal production faces strong competition by price subsidies for imported cereals. Agricultural exports (cotton, fruits & vegetables, livestock) to neighbouring countries with high purchasing power increase the area under production.
Traditions: Water allocation rules are based on Islamic principles which are slow to adapt to the altering conditions created by a modernising society. Scarce water resources are therefore not necessarily allocated according to efficiency criteria.

Research Objectives

The study aims at helping Yemen to find ways of attaining greater efficiency in the planning process concerning management of natural resources, particularly management of water as an agricultural input. A decentralised approach shall provide local solutions for local problems. Therefore the study first of all aims at helping to understand the local conditions and peculiarities of agricultural sector management in the project region. Based on this analysis the Wadi Tuban Model (WaTuMo) shall provide decision makers in Yemen with an analytic and planning instrument that delivers relevant information concerning development strategies in agriculture. The policy options considered in the model are based on the Ministry of Agriculture's guiding principles for the future of agricultural development in Yemen as laid down in "The Aden Agenda" in March 1997 (MAWR, 1997).

Theoretical Background

The hypothesis of profit maximising producers and utility maximising consumers is reflected in the Consumer and Producer Surplus principle (Samuelsonian objective function) as shown in figure 2 (HAZELL, 1986). In the market equilibrium (quantity Q_0 and price p_0) consumer surplus (CS triangle) can be calculated as consumers' willingness to pay (area underneath the demand curve) minus the market value of the good (quantity Q_0 times price p_0). Producer surplus (PS triangle) amounts to the market value of the good (quantity Q_0 times price p_0) minus the goods' cost of production (area underneath the supply curve). By maximising the sum of CS and PS a Pareto optimum for welfare can be derived, which, however, does not give regard to the individual contribution of CS and PS respectively.



P: Price of commodity
Q: Quantity of commodity

P_0: Equilibrium price
Q_0: Equilibrium quantity

S: Supply curve
D: Demand curve

CS: Consumer surplus
PS: Producer surplus

Figure 2. Principle of Consumer Surplus and Producer Surplus in the domestic economy

If price-responsive supply functions (i.e. the supply curve shown in figure 2) for individual commodities are not known, regional supply functions can be employed in the form of regionally aggregated cost functions which cover marginal variable production cost (linear) and the (non-linear) cost of scarce resources like traction, labour and water.
The calculation of consumer surplus plus producer surplus can accordingly be reduced to "Willingness to pay" (WTP) less "Aggregate Cost of Production". Figure 3 illustrates how the parameters for the inverse demand function (intercept α and slope β) can be derived from observed prices and quantities in equilibrium together with ε, the own-price elasticity of demand. Using these parameters the area under the demand curve (WTP) can be calculated according to Eq.(1)- Eq.(4):

$$P_{implicit} = \alpha + \beta \cdot Q \qquad (1)$$

where:

$$\alpha = P_{observed} - \frac{P_{observed}}{\varepsilon} \qquad (2)$$

$$\beta = \frac{P_{observed}}{Q_{observed}} \cdot \frac{1}{\varepsilon} \qquad (3)$$

with:
P = commodity price
α = intercept of inverse demand function
β = slope of inverse demand function
ε = own price elasticity of demand
Q = demand for commodity

so that:

$$WTP = (\alpha * Q_0) + (½\, \beta * Q_0 * Q_0) \qquad (4)$$

$$P_{implicit} = \alpha + \beta \cdot Q \qquad (1)$$

where:

$$\alpha = P_{observed} - \frac{P_{observed}}{\varepsilon} \qquad (2)$$

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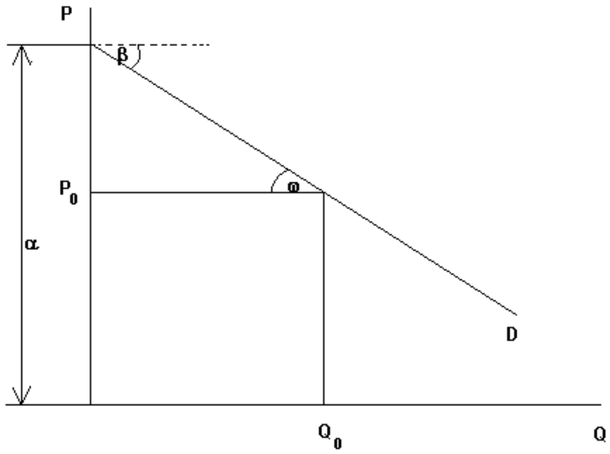

Figure 3. The inverse demand function and its parameters

Interregional trade helps each participating region to make best use of comparative advantages and/or to overcome particular disadvantages. Trade will affect producer surplus and consumer surplus and effect in increases in total welfare.
Risk may affect farm households in a variety of ways such as production risk (yield variability), marketing risk (commodity price variability) and even political risk (insecurity of land tenure). But also on the regional (or macroeconomic) level risk factors are of importance, as they may have an effect on food security, price stability or even on natural resources. Uncertainty, especially with regards to the high variability of irrigation water availability, has to be accounted for in the planning process on the farm level as well as on the regional level.

Data Collection
Micro-level data, i.e. “quantitative and qualitative parameters which collectively describe the structure and function of farm-household and rural community systems” (UPTON ET AL., 1994) were collected on the crop level (surveyed plots), well level (surveyed wells), household level (interviewed households), market level (Aden wholesale market survey) and institutional level (expert consultations).
In the crop survey 145 plots were selected following quota for regions and crops. 91 and 34 annual crops were surveyed in the Kharif season (winter 97/98) and the Seif season (spring 98) respectively. In addition 20 plots with perennial fruit trees were surveyed. Field enumerators paid weekly visits to the plot owners to collect quantitative and qualitative information on all agricultural activities on these plots. Each plot’s area was measured by triangulation method with a theodolite.
The discharge of 29 sample wells was measured in the well survey using portable water meters. Water salinity measurements were repeatedly done for the 29 wells in the sample. Two wells where the owners had agreed on permanently installing water meters were monitored with respect to water management (quantities pumped and water utilisation).
Household interviews were held with 55 farmers in order to gain information on farm sizes, production structure, livestock elements, available resources (land, labour, capital), but also on the importance of non-agricultural activities.
An Aden wholesale market survey aimed at gathering price and quantity information for agricultural commodities. For one year data were collected on a daily basis.
Expert consultations and a workshop were held with representatives from various governmental and private institutions to get information about the respective institution’s role

concerning water resource policies and in order to identify policy goals and applicable policy instruments in Yemen.

Data Analysis / Modelling Approach

In contrast to farm models - which usually operate with a set of fix prices - sector models allow for dynamic prices as they take into account market mechanisms and policy interventions. They further allow to describe the reaction of actors to changing conditions (positive economics). WaTuMo was set-up as a ”regionalized agricultural sector model ” using the GAMS (General Algebraic Modelling System) software package. The diversity of farming systems *within* Wadi Tuban made it necessary to divide the region into three homogenous sub-regions, each represented by one ”regional farm” with aggregate resources and production technology based on the results from the surveys in the three corresponding villages AlChodad, AlMajhefah and AlFeyoush. The sub-regions differ in key characteristics like prevailing production structure, degree of co-operation between water users and well owners, frequency of flood-water (sayl) assignments and depth to groundwater. In addition Aden is modelled first as a consumption region (including exports) and secondly as a virtual production centre when imports enter through the port of Aden. WaTuMo’s general structure is shown in figure 4.

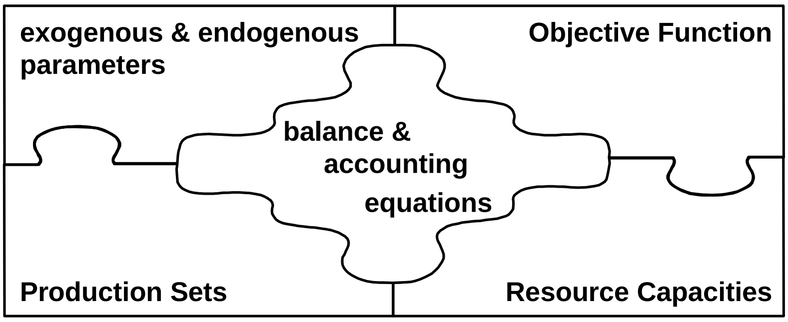

Figure 4. WaTuMo - General structure of the Model

Objective function

WaTuMo employs the principle of maximising consumer and producer-surplus (CPS) to model welfare effects on domestic markets. In addition to CPS a foreign trade component is used (see Eq.(5)).

$$MAX \quad (\text{CPS} + \text{Export Earnings} - \text{Import Costs}) \quad (5)$$

External costs (e.g. those caused by groundwater overuse) could theoretically have been formulated inside the objective function, but such an ex-ante quantification would include a considerable amount of error prone ”value judgement”. Instead this study employs an ex-post approach to assess sustainability.

Resource capacities

Each of the three production regions in the model is represented by one hypothetical farm which has the aggregate factor supply of the respective subregion. In total the model sums up 2200 farms in the region with approximately 9000 ha agricultural area and 250 tractors. Tractor capacity is supplemented by animal traction according to the number of cattle/camels (activity variable). Besides family labour the farms can employ two types of hired labour: casual labour, hired on a monthly base, or seasonal workers who are contracted for at least three months (activity variable). Irrigation water is provided from two sources: overall availability of surface water in the Wadi is assessed on a monthly basis, with data stemming from a 8-years time series (1973 to 1980). Actual availability of surface water at regional level depends on an allocation share (activity variable). Availability of groundwater for irrigation depends on the number of wells (activity variable). In the model the activity of wells can either be determined from outside (assuming a fixed number of wells being in operation and varying the amount of water pumped from these wells only) or well activity is internally determined by an investment decision.

Production Sets
In WaTuMo 38 different production sets for 10 annual field crops, 5 permanent crops and 4 animal production systems are defined via their demand for the scarce inputs ”arable land”, ”traction”, ”labour” and ”irrigation water”. The time scale is the calendar month. Demand for other inputs (e.g. seeds, fertiliser, pesticides) are monetarised and attributed to the production sets as lumpsum costs regardless of time. The same applies to physical yields of the main product and by-products.

Exogenous and endogenous parameters
The hydrological component of WaTuMo is determined by the following parameters: Gross water supply is given by the occurrence of flood water in the Wadi, average annual precipitation in the survey area, the pumping capacity of groundwater wells in the region and water ”imported” from outside. Water demand is given by runoff of extreme floods to the sea, water loss through evaporation, crop evapotranspiration and the amount of water used for domestic and industrial purposes. Flood water allocated for agriculture will only partially be effective for irrigation, as looses occur during conveyance in the Wadi and in canals. The further water is conveyed the higher the proportion of water which will infiltrate the soil and finally recharge groundwater. Similarly a considerable share of finally applied irrigation water will again recharge groundwater.
Parameters affecting the economical component of WaTuMo are either in the ”Marketing” group or in the ”Policy” group. Market parameters (1997/98 prices, quantities and own-price elasticities) of locally traded commodities are used to compute demand functions, based on which CPS is calculated. Transport costs consider distance between production and consumption region as well as transport cost premiums for highly perishable vegetables and milk. Policy parameters affect the price of diesel, interest rates for credit, duties on imported well equipment, flood water allocation rules and flood water fees.

Balance and accounting equations
While maximising the value of the objective function the activity of production sets is subject to several balance equations which result from the scarcity of resources (land, labour, water), the internal balancing of intermediate products (e.g. fodder production – animal production – milk production) and finally the balance of supply and demand in each of the three consumption regions, which is achieved by local production in combination with transport (activity variable) between regions.
Moreover, accounting equations (which do not actively affect the model) calculate, for example, commodity prices in market equilibrium, individual and aggregate cost components of agricultural production, regional agricultural labour demand, contribution of agriculture to foreign trade and accounts of regional water use. These figures also provide indicators for assessing the various aspects of sustainability.

Limitations of the modelling approach

The model is restricted in a number of ways, out of which the regional limitation should be noted first of all. As the field data stem from observations only made in Wadi Tuban, care should be taken to generalise findings and apply them to other regions or Yemen as a unity. A second limitation is the static nature of the model, which does not allow inter-temporal modelling and integration of e.g. demographic changes, changing traditions, technical progress or path dependencies. Instead, these issues have to be dealt with qualitatively. Third, some important simplifying assumptions underlying this model need to be mentioned as well, like "factors are fully mobile within each sub-region", "inputs can be perfectly divided", „own-price elasticities of demand were properly estimated"...

Selected Results

Model Performance

WaTuMo was calibrated based on the data material collected during the 1997/98 agricultural season. The overall picture of "reality" could be reproduced by the model with sufficient accuracy, i.e. the endogenously determined activity variables in the model (e.g. crop acreage, livestock numbers, number of wells, groundwater overuse, market prices, agricultural employment) were in the range of the own survey data and/or secondary data.

Sources, quantities and cost of irrigation water

Farmers in the survey region use two different sources of water for irrigation.

1) Flood water (Arabic: Sayl), which is allocated through the Irrigation Department at a fee of 0.005 US$ per cubic meter – to grow sorghum, cotton and watermelon

2) 60 million cubic meters of groundwater per year which is pumped from privately owned wells reaching up to 90 m in depth, mainly to produce fruits and vegetables. Variable cost of pumping is between 0.005 and 0.015 US$/$m^3$ (depending on pumping depth). Depreciation for wells and pumping equipment adds another 0.005 to 0.015 US$/$m^3$ (depending on pumping depth and average utilisation). A value of 0.02 US$/$m^3$ presents a typical figure for the total cost of pumping groundwater in the region.

Analysing policy scenarios

While keeping the modules for "objective function", "resource capacities", "production sets" and "balance & accounting equations" unchanged, policy scenarios were formulated by modifying the respective exogenous parameters in the model (see table 1). Policy options not incorporated in the model are administratively set limits on production area for certain crops or "command and control" practices concerning the operation of wells, as the enforcement of such policy options is infeasible under the current situation in Yemen.

Table 1: Policy scenarios implemented in WaTuMo

Parameter	Values	Number of scenarios
Diesel Price	5 YR/l – 20 YR/l	16
Well equipment subsidy Well equipment duty	80% - 60% - 40% - 20% - 0% 0% - 20% - 40% - 60%	8
Flood water fee	0.005 – 0.01 – 0.05 – 0.1 YR/m^3	4
Water allocation rules *	ChMaFe, ChFeMa, MaChFe, MaFeCh, FeChMa, FeMaCh	6
Path dependencies	Fixed number of wells Variable number of wells	2
Total		6144

* Ch = subregion1 (AlChodad), Ma = subregion2 (AlMajhefah), Fe = subregion3 (AlFeyoush)

Little impact on groundwater abstraction (see figures 5 and 6 – shaded area) can be expected from the latest diesel price increase (from 5 to 11 YR per litre in 1998). With higher groundwater costs vegetable area would significantly decrease (see figure 5) while cotton production (see figure 6) is likely to substitute for vegetables as the crop makes efficient use of surface water. From around 19 YR per litre water demand would no longer exceed renewable supply, but the total welfare decrease caused by such a policy (19 YR/l instead of 5 YR/l) would amount to 4.7%. Prices of vegetables would rise by up to 43 % whereas prices for fruits and animal products are less affected by the policy change. Per capita consumption will decrease by 5% for vegetables and 7% for fruits. Total household spending for primary agricultural commodities would increase by 1 %.

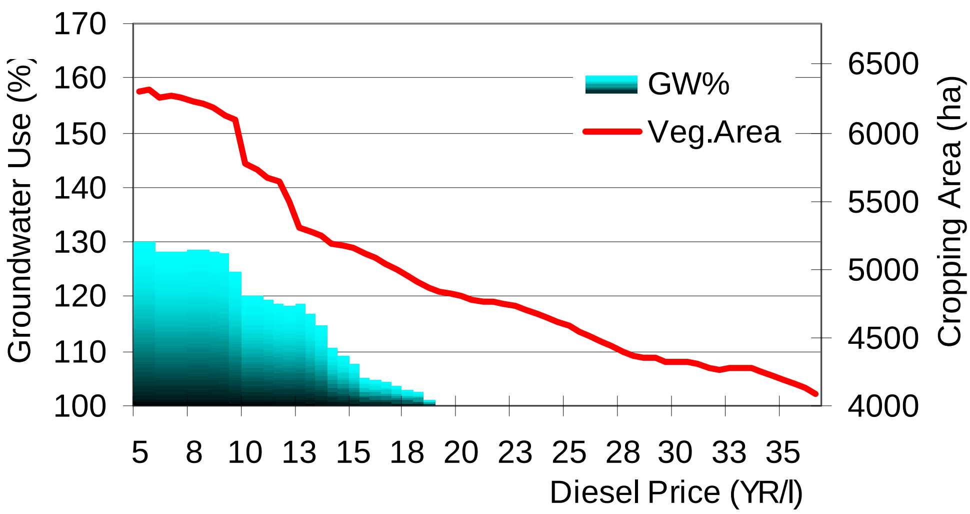

Figure 5. Effect of diesel price increase on groundwater use and vegetable area

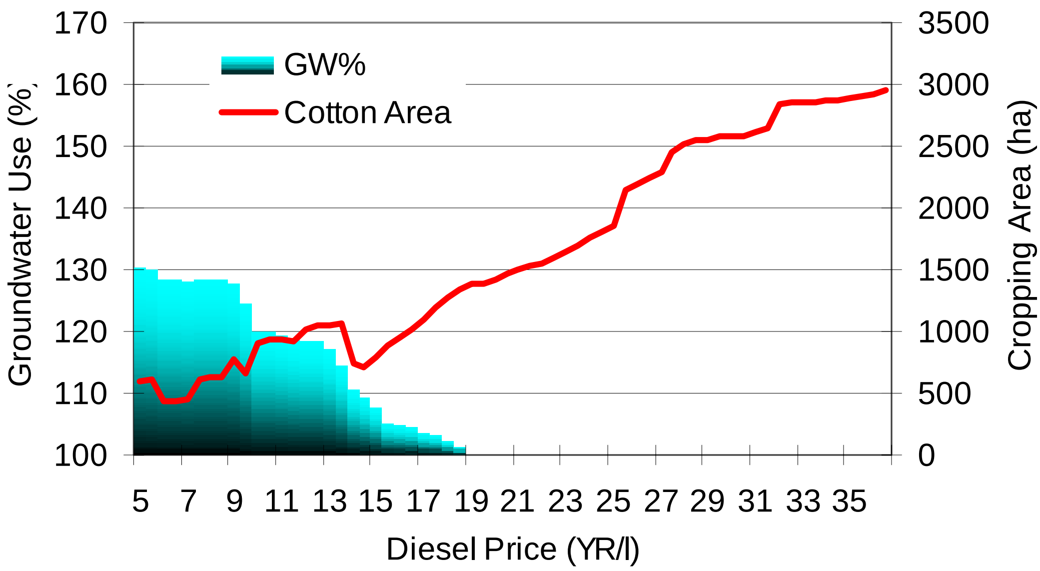

Figure 6. Effect of diesel price increase on groundwater use and cotton area

A diesel price increase is likely to have a positive effect on employment in agriculture, particularly where farmers' access to subsidised irrigation technology is limited. On the other hand imposing a tax on pumping equipment will harm employment if diesel prices remain on subsidised levels. However, a combined application of the two instruments (removal of diesel price subsidy and imposition of tax on pumping equipment) along the trajectory path shown in figure 7 can be expected to contribute to both ecological and social sustainability.

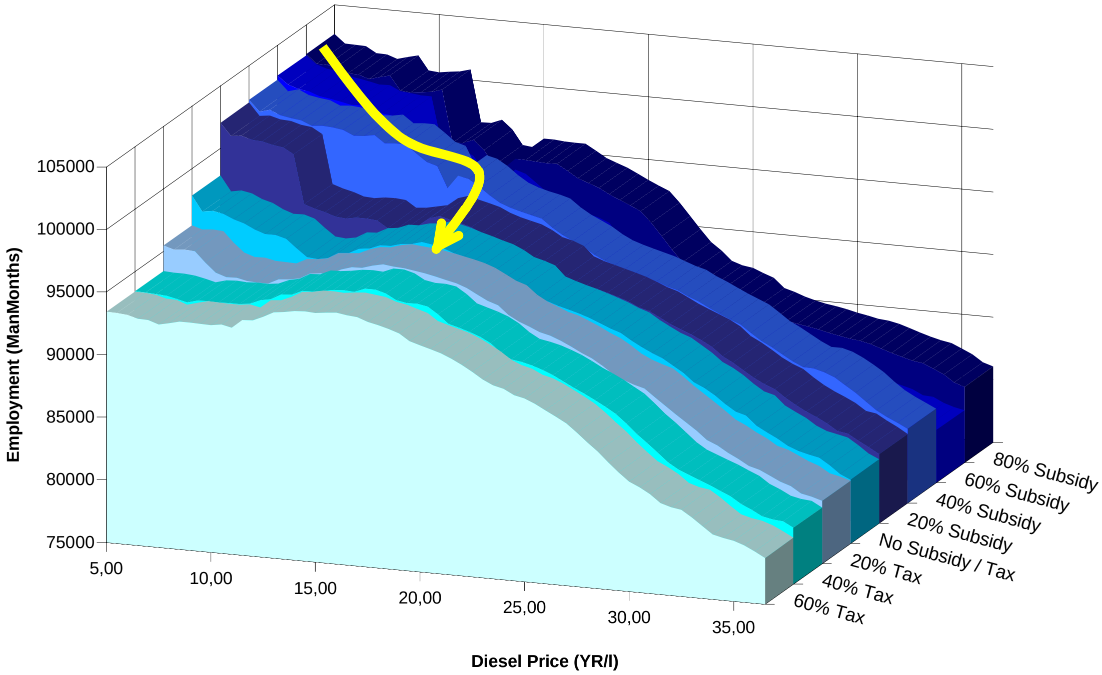

Figure 7. Effect of Diesel Price and Investment Subsidies/Taxes on Employment

Conclusion

Preliminary results indicate that the sole implementation of a single policy measure will be unlikely to create a win-win-win situation concerning ecological, economic and social sustainability and finally put an end to overusing the groundwater aquifer in the survey region.

Even a well-designed policy-mix would create a double-dividend effect only at the cost of reduced welfare (less consumption caused by agricultural commodity price increases). Unfortunately it must be doubted whether the Yemeni society today is able and willing to shoulder this burden.

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