Modeling Population-Environment-Development-Agriculture Interactions for Science Policy Communication and Advocacy in Africa: the PEDA model

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Abstract

Context
The United Nations conferences of the 1990s drew attention to the world's major developmental challenges. Each of these challenges, notably environmental degradation and depletion of natural resources, population growth, the inequality of women and food insecurity are generally more pronounced in Africa than in any other region of the world. In addition, many studies have shown, that all these elements are part of a web of strong and intricate causal relationships that often reinforce each other. Today, there is not only a need for a better understanding of these interactions, but also one for urgent action to reduce the negative impact of these synergies on African economies.

Methods
The Economic Commission for Africa (ECA) supports its member states to focus on these long-term sustainability issues. It promotes a change in policy-making to shift from a sectoral approach to holistic planning that includes concerns about population growth, the status of women, agricultural production and the state of the environment in their development plans. The search for new ways to engage policy-makers' attention on these issues led to the creation of a powerful advocacy tool, the Population-Environment-Development-Agriculture (PEDA) model. The model has been developed in a collaborative effort between the ECA and the International Institute for Applied Systems Analysis (IIASA).
PEDA is an interactive computer simulation model demonstrating the medium to long-term impacts of alternative policies (including policies on HIV/AIDS) on the food security status of the population. As food security is a factor of developments in the areas of population, the environment, agriculture and socio-economic development, the model demonstrates the relationships between these fields as well.
The simulation exercise in PEDA consists of three steps. First, (multi-state) population projections are carried out to determine the size and characteristics of the population. Simultaneously, the model estimates the food availability as the sum of food production and net trade. Agricultural production is considered as factor of the natural resources stock (land and water); the size and productivity of the labour force and technological inputs and innovations in agriculture. In a third step, the estimated available food is distributed over the population following a non-linear food distribution curve to determine the fraction of the population that will be food insecure.
The output variables of PEDA range from the classic demographic parameters, to indicators of land degradation, agricultural production and socio-economic development.

Results
The PEDA model will be illustrated through an application for Ethiopia for which some alternative development scenarios are compared.
The model provides indicative answers to policy questions such as 1) what is the effect of increased education on the environment and land degradation? 2) How does a decline in fertility rates influence agricultural production? and 3) what is the impact of HIV/AIDS on agricultural outputs?

Conclusion
The PEDA model is one of the first efforts to explicitly quantify and illustrate the population development environment agriculture interrelationships on the national level. It is expected both to contribute to an academic discussion on the issues, as well as to support the formulation of better-integrated development policies in African countries.

1 Background

The last two decades, Africa experienced a severe crisis manifested among others in the constant decline of its economic growth rate. Since 1994, the economic situation of the continent has improved steadily, but this resumption is still below the necessary level to have a significant impact on poverty. Although the proportion living in extreme poverty in Africa may have declined with a few percentage points in the last couple of years, high population growth rates mean that the absolute number of poor still increases dramatically on a daily basis. Additionally, Africa's economic performance seems to be highly dependent on the international economic environment and weather conditions; two exogenously determined factors that do not embody any guarantee for future growth (UNECA, 1999). Two basic pressures account for the continued deterioration in the quality of life in Africa. First, the population growth rate exceeds that of economic growth and food production in most African countries. Additionally, the rapid deterioration of the environment on the continent prevents the desired increase in agricultural productivity. Today, over three-fourths of sub-Saharan African countries produce less food per capita than they did in the 1980s. Daily calorie availability is well below the recommended minimum and as much as 30-40 percent of the population is undernourished. Malnutrition affects even more people.

Inspired by the notion of sustainable development, there is increasing understanding of the necessity to go beyond the traditional sectoral approach in national development planning. It has been demonstrated that, at least in the medium to long run, a country's economic performance and the food security of its citizens are closely related to its demographic and educational trends as well as to the health of the natural environment. Since these issues are closely interconnected in the real world, they should also be viewed together in national politics and development planning. The scientific understanding of mutual interdependencies is, however, not yet sufficiently reflected in the political institutions of individual countries. There is tremendous inertia in such systems, partly due to the traditional training of experts that is often characterized by compartmentalization of disciplines, and partly to the fact that the impact of developments in one sector is often invisible in another sector in the short term.

Hence, convincing policy makers and country experts of the negative synergy arising from the interconnections of population growth, environmental deterioration and declining agricultural production is a major objective of the Food Security and Sustainable Development Division (FSSDD) of the United Nations Economic Commission for Africa (UNECA). With that goal in mind, the FSSDD engaged itself to develop a computer simulation model intended to illustrate the interactions between population changes (P), the environment (E), socio-economic development (D) and agriculture (A). In this paper, we present a theoretical introduction to the PEDA model as well as an illustration of its application to Ethiopia.

2 PEDA, in brief

PEDA is an interactive computer simulation model (developed for a windows environment), demonstrating the medium to long-term impacts of alternative national policies on the food security status of the population (Lutz & Scherbov, 2000). Through the manipulation of scenario variables, the model enables the user to project the proportion of the population that will be food secure and food insecure for a chosen point in time. As food security is a factor of developments in the field of population, agriculture, the environment and socio-economic development, the model demonstrates the relationships between these fields as well. The current version of the PEDA model includes the results of the first experiments to introduce an HIV/AIDS component and to illustrate its impact on the other variables in the model. As such the PEDA model is able to give answers to a wide range of policy questions regarding the nexus interactions (see box 1).

Box 1: policy questions

“What is the impact of increased education on the environment and land degradation?“
“How does a decrease in fertility rates influences the agricultural production in a country?”
“What is the impact of HIV/AIDS on agricultural outputs?”
“What will be the effect on the food security status of the population if the government took measures to increase fertiliser and machinery use in agriculture by 2% a year?”
“What will be the impact on the food security situation in a country if the educational enrolment rates would immediately be brought up to 75% for both sexes?”

As a model with a focus on a specific chain of interactions, the mission attributed to PEDA at its conception was one of advocacy: illustrating the negative development spiral resulting from high population growth, environmental degradation and decreasing per capita agricultural production. It is to demonstrate the magnitude of existing interactions and to suggest alternative policy strategies to break this vicious circle in African countries. Since its conception and after several rounds of evaluation and review, the different components of the model have grown and have been refined steadily to support ambitions that may exceed its advocacy function. However, the degree to which PEDA can be actually used as a prediction tool to concretely support policies of a given country is not yet clear. For that purpose more sensitivity analysis is needed and more, better and country specific data need to be collected and fed into the model. This is an effort for which the ECA invites research institutes and universities to collaborate in an effort to improve the value of the PEDA model for concrete policy support.

The model can be used at two different levels. Initializing the model for a new country would ideally be the job of a team of experts with specializations in demography, agriculture and natural resources modeling and with sufficient computer skills. However, once the model has been initialized for a specific country, persons with basic computer skills can easily make projections themselves and test the effect of alternative policy scenarios on the food security status of the population. The two different users levels are also reflected in the software structure. Most users will restrict themselves to the options available in the standard user interface. For more advanced tasks such as initializing the model or for manipulating some of the advanced parameters, the user needs to go beyond the user interface.

3 Theoretical foundations the structure of PEDA

3.1 The theoretical inspiration for PEDA

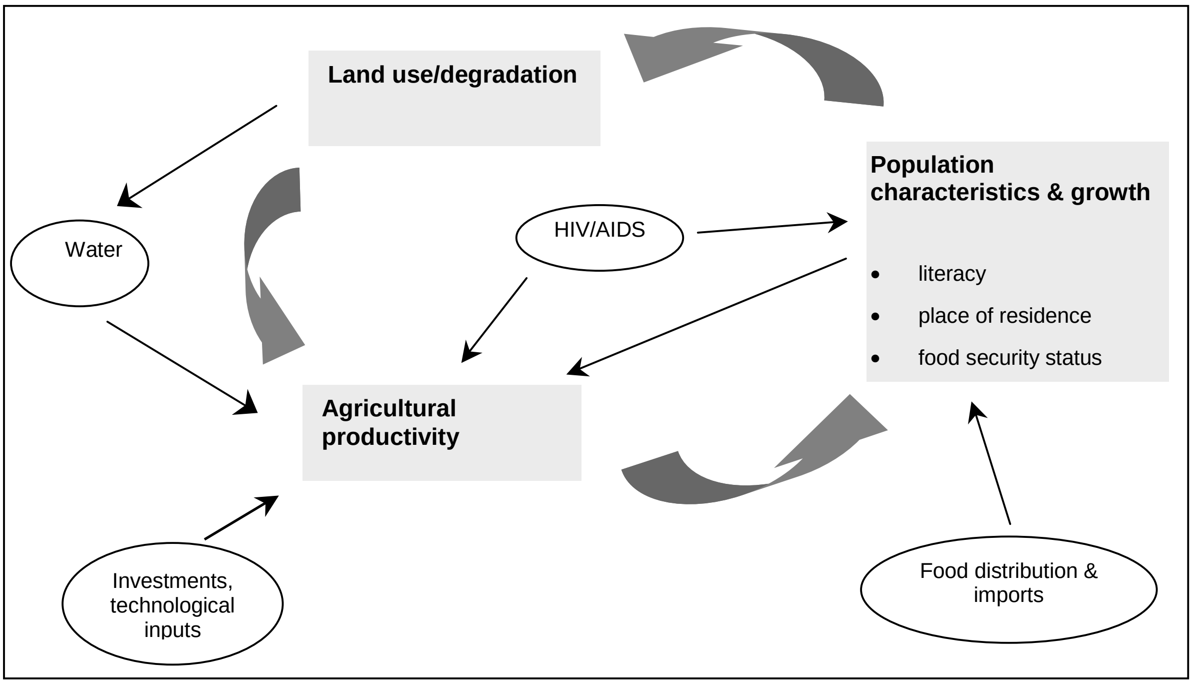
A theoretical construction, often labeled the “vicious circle model,” has become an influential paradigm in the discussion around population, poverty, food security and sustainable development. It essentially assumes that high fertility, poverty, low education and status of women are bound up in a web of interactions with environmental degradation and declining food production in such a way that stress from one of the sources can trap certain rural societies, especially those living in marginal areas, into a vicious circle of increasingly destructive responses. One illustration of this mechanism is the parable of firewood (Nerlove 1991). In many countries the collection of firewood takes a lot of time, and more children can help to collect more firewood. But this leads to less firewood near the villages, increasing degradation of the natural resource and the desire for more children to go help collecting firewood from greater distances, thereby also depriving children from educational opportunities. Dasgupta (1993) presents this argument in a more generalized form. The condition of poverty and illiteracy of the households concerned, prevents substitution of alternative fuel sources or alternative livelihoods. A gender dimension is added through the fact that the status of women and girls worsen because of the increasing amount of time and effort that they must devote to daily household tasks (Agarwal 1994; Sen 1994). The result is faster population growth, further degradation of the renewable resource base, increasing food insecurity, stagnating education levels, and yet a further erosion of women's status. From a theoretical point of view this vicious circle model is a useful contribution towards a unifying framework in causally linking fertility, poverty, low female status, environmental degradation, and agricultural efficiency.

In terms of its empirical relevance, the vicious circle assumption is more controversial. Because the economic reasoning of this model largely operates at the household level, empirical studies on the issue have been mostly confined to that level and reached mixed results. At the macro level of different population segments this model could be very relevant --particularly in the African context-- although some of the assumptions of the stricter version of this model are empirically unconfirmed and controversial. Especially the assumption that environmental degradation may actually lead to increases in fertility is difficult to be defended at a time when fertility rates are rapidly falling all over Africa within a context of degrading environmental resources. This does not necessarily imply that the assumed effects are entirely absent, but it seems to imply that if they operate, they are overlaid by the powerful and dominating processes of the demographic transition. Hence, it may be reasonable to alternatively assume that food insecurity is associated with a slower decline in fertility, although under certain conditions and in the short run famines may well induce declining fertility. Whatever the position on this issue, the PEDA model as outlined below is flexible enough to represent alternative assumptions through alternative parameter choices and scenarios.

3.2 The structure of the PEDA model

As illustrated in Figure 1, the PEDA model consists of three sub modules or segments: a population module, a natural resources module (land and water) and an agricultural production module. Although not immediately visible to the user of PEDA, the model contains an additional food distribution segment that accounts for the inequality in the access to food.

Figure 1: the structure of the PEDA model



The vicious circle in PEDA operates through the negative impact of a fast growing population on the natural resources stock, which in its turn decreases agricultural production and that again induces more food insecurity. This negative chain of interactions is, however, not part of the model structure itself. As will be highlighted in section 3.3, the user can easily change the assumptions of the relationships between population growth, the natural resources stock and agricultural production.

In the population segment of PEDA, multi-state population projections are carried out to determine the size of the population by urban-rural place of residence, literacy status and food security status. The food production and availability in PEDA is influenced by a set of endogenous and exogenous variables. An important resource for agricultural production is land. Although the user can omit this effect, the model by default assumes a negative impact of population growth on land. Agricultural production is further influenced by the size and qualification level of the labour force, the availability of water, and efforts in fertilizer and machinery use. The contribution of water to agricultural outputs is dependent on climatic conditions but also on the status of the land degradation and efforts in irrigation and water management (building of reservoirs).

In addition to the produced food, the model allows to account for post-harvest losses and for food imports and exports to estimate the net food availability. In the last step the available food is distributed over the population following a non-linear food distribution function to determine the proportion of the population that is food insecure.

Recently, an HIV/AIDS component has been added to PEDA to account for its demographic impact through excess mortality and for its negative impact on agricultural production through the reduction of the labour force because of HIV/AIDS related illnesses.

The different segments in the PEDA model touched upon briefly above are treated more in detail in the sections 3.4 through 3.9. An even more elaborate treatment of the different aspects and features of the PEDA model can be found in the PEDA Technical Manual (UNECA, forthcoming).

3.3 Vicious versus virtuous circle dynamics

Although the PEDA model is flexible with regard to the underlying theoretical assumptions, by default it is set to be compliant with the main principles of the vicious circle at the macro-level described earlier; i.e. that the growth of the (illiterate and food insecure) population in rural areas contributes to the degradation of land, thus lowering agricultural production and further increasing the number of food insecure. If not broken, this vicious circle would lead to ever increasing land degradation and increases in the food-insecure population. The model does not assume increasing fertility as an automatic response to food insecurity, which is the most problematic part of some vicious circle models. Rather, the food secure and food insecure fractions of the population are assumed to have different fertility levels (subject to exogenously-defined trends) and hence the aggregate fertility level only responds to changes in the food insecurity through the changing weights of the groups in the calculation of the overall fertility.

The vicious circle can be broken through several possible interventions in the field of food production, food distribution, education, environmental protection and population dynamics and thus allowing for more Boserupian visions on the nexus of population, the environment and agricultural production. The power of the PEDA model is that these assumed positive or negative interactions are all part of the scenarios that can be set by the user and not hard-wired in the model.

More optimistic projections can, for example, be carried out by defining scenarios that assume no negative (or even a positive) effect of increasing population densities on the natural resources stock, or increasing technological inputs in agriculture (e.g. fertilizer, machinery or irrigation), etc.

3.4 The population segment

PEDA is different from most macroeconomic models in that it uses a population-based approach. The population-based approach views human beings with their specific characteristics (such as age, sex, education, health, food security status, place of residence, etc.) as agents of social, economic, cultural and environmental change. But the population is also at risk of suffering from repercussions of these changes and of benefiting from positive implications. In this sense, human beings are seen as a driving force of these changes and the first to be affected by the consequences of these changes. Economics, if it comes into the picture, e.g. through the importance of markets in distributing goods, plays only an intermediate role and economic indicators are not seen as the primary objective of the modeling exercise. In this sense, the population-based approach differs from much of the development-economics literature.

The population-based approach does not assume that population growth or other demographic changes are necessarily the most important factors in shaping our future. Instead, the phenomena that we want to model are studied in terms of different characteristics that can be directly attached to, and (at least theoretically) measured with individual members of the population. Characteristics such as age, sex, literacy, place of residence and even nutritional status can be assessed at the individual level. The sum over these individual characteristics makes up the distribution of the total population. In using these individual characteristics, PEDA distinguishes itself from models that rely on other frequently used economic indicators such as the GNP per capita. Although the GNP it is indicative of the average amount of money that an individual has in his/her pocket, it cannot be directly measured at the individual level. It results from aggregated indicators of national accounting with various conceptual and measurement problems. Although many of the powerful quantitative economic tools (such as general equilibrium models) cannot be applied due to this choice of approach, other very powerful but less well known tools of demographic analysis and projection can be applied. The tools of multi-state population analysis allow for the projection of the population by several characteristics (such as age, sex, education and place of residence) at the same time. Multi-state projections group all individuals of a given population into different sub-populations which are then simultaneously projected into the future, while at each time interval, people can also move from one sub-population to another.

In PEDA the population is broken down into eight sub-groups according to urban/rural place of residence, educational and food security status. Place of residence and food security status are core elements of the vicious circle reasoning as mentioned earlier. Significant educational fertility differentials give the explicit consideration of education in the model a strong rationale (see Lutz, *et al*. 1999), but there is also abundant literature on the significance of literacy to both agricultural production and land degradation (e.g. Lutz, ed., 1994).

Each of these eight sub-groups is further subdivided by age (in single-year age groups) and sex, i.e. every one of the eight groups has its own age pyramid. During each one-year simulation step, a person will move up the age pyramid by one year within the same sub-group, or move to another sub-group while aging by one year (or die). It is also possible for some people to make multiple transitions within one time step, e.g. from rural/food insecure/illiterate to urban/food secure/illiterate. For education and rural/urban migration, the model is hierarchical, i.e. people can only move in one direction, from lower to higher education and from rural areas to urban areas. Movement between food security states can happen in both directions, depending on the food conditions in the relevant year and the food distribution function.

This PEDA population module is in itself a useful piece of software for multi-state population projections. As part of the initialization process, the user can set for each of the eight states, age and sex-specific fertility, mortality and educational transition rates. As scenario variables, dynamic future paths can be defined for fertility and mortality. The model automatically adjusts age-specific fertility and mortality patterns according to the levels of the total fertility rate and life expectancy chosen for each year. The methods of multi-state population projections are well described in the literature (e.g. Rogers, 1975; Keyfitz, 1979 and Scherbov & Grechucha, 1988). Here it is sufficient to mention that the multi-state population projection model is a generalization of the one-dimensional cohort-component model of population projections that takes into account transitions that occur between different states.

Education and rural-urban migration are defined in terms of the proportion of male and female cohorts that will become literate and move from rural to urban areas. While education is concentrated in childhood, rural-urban migration tends to follow a typical pattern with highest migration intensities in young adulthood. For this a standard internal migration schedule has been applied (Rogers and Castro, 1981). In the current version of the PEDA model, both education and internal migration are treated statically. That is, the user can set a specific transition rate and that remains constant throughout the projection period. With respect to education, the models allows for sex and age specific educational transition rates.

The PEDA model also accounts for the demographic and developmental consequences of the HIV/AIDS pandemic. This is dealt with in greater detail in section 3.9 of this paper.

3.5 Land

Land (arable land and pasture) is a key environmental resource for agricultural production. Like many of the variables that affect agricultural production, land is treated as an index variable set to 1.0 in the starting year. This value must be seen as describing both the quantity and quality of land. In a more general manner, one can label the land variable as 'the natural resources stock'. The change in the stock of natural resources *R(t)* is the result of a combination of indigenous growth or regeneration *g(R(t)),* and a reduction through population induced environmental degradation *(D(t)):*

$$R(t) = g(R(t)) - D(t)$$

Whereby R(t) for the initial year is equal to 1 and indigenous growth or regeneration is defined as:

$$g(R(t)) = a(\overline{R} - R(t))$$

Herein, parameter *a* reflects the speed at which the resources recover. However, it is assumed that the pace of resource recovery diminishes as the saturation level ($\overline{R}$) is approached. The saturation level stands for the stationary solution of *R* if the resources are not degraded. The saturation level has to be chosen in accordance with the specific conditions in the country of application and remains constant over the whole projection period.

The model allows the user to assume that it is especially the rural illiterate food insecure segment of the population that depletes natural resources in their quest for survival. As this is often used as an assumption in natural resources modeling, this impact diminishes as the stock of resources decreases. In mathematical form this is given by:

$$P_I(t)\frac{R(t)}{R(t)+\eta}$$

Whereby $P_I(t)$ stands for the relative change in the number rural-illiterate-food insecure population compared to the starting conditions. η is a constant factor that has a default value of 4.

The scale of environmental degradation is also a function of the change in the overall population density. Mathematically, this is expressed as:

$$\frac{P(t)}{\overline{R}}$$

Whereby P(t) stands for the relative change in the total population compared to the initial year. The denominator reflects the upper limit of the natural resource stock and has a constant value that is country specific and reflects the relative status of the resource stock in the year for with the initial data are prepared.

The complete mathematical expression for environmental degradation (D(t)) is thus:

$$D(t) = \gamma \frac{P(t)}{\overline{R}} P_I(t) \frac{R(t)}{R(t)+\eta}$$

The only parameter not yet described in this function is γ. This parameter is called the land degradation impact factor in PEDA and influences the intensity of the effects described above. The value of γ can be adjusted in the PEDA user interface. Although the value of γ is subject to country specific conditions, by default it is set to equal 0.02. Setting the value of γ to 0.00, implies that there is no assumed negative effect of increasing population densities on the natural resources stock. For experimental purposes, the user could also set a negative value for γ, meaning that increasing population densities have a positive effect on the natural resources stock, but in that case the natural resources upper limit ($\overline{R}$) may be easily exceeded.

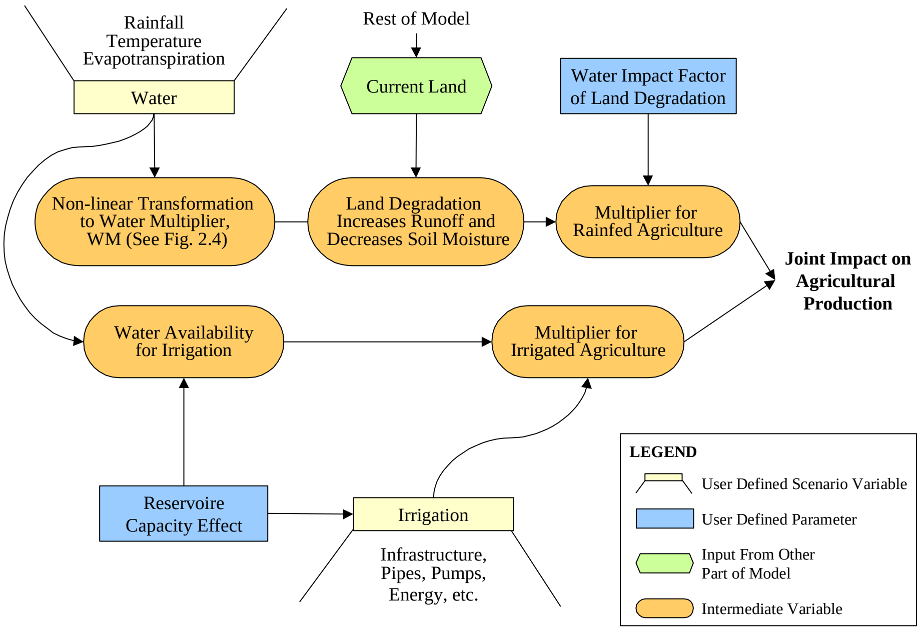
The expression of land degradation used here implies that if resources are completely degraded (i.e. R(t)=0), the value of D(t) will be automatically zero as there is nothing to be depleted. Similarly, if the stock of rural illiterate food insecure population is zero, environmental degradation will be zero as well.

In each year, the adjusted index value of current land enters the agricultural production function with the elasticity described below (see section 3.7).

3.6 Water

For its key role in food security and sustainable human development, water deserves particular attention in models dealing with the nexus issues. In the PEDA model, water is treated in a separate module with an eventual multiplier effect on agricultural outputs. In its current form, the water module contains two externally defined scenario variables (water and irrigation) that can be changed dynamically and two user defined parameters: the reservoir capacity effect (RCE) and a parameter specifying the impact of land degradation on water availability (subsequently labeled as the water impact factor, WIF). The value of the latter two parameters should ideally be determined during the process of initialization although different values can still be defined by an advanced user as part of the scenario settings. The water segment in PEDA also relies on the input from other variables in the model such as the quantity and quality of land and calculates a number of intermediate variables. This input is completely endogenously determined and cannot be manipulated by the user.

Figure 2: the water module



The water module essentially has two parts, one referring to rain fed agriculture, and the other to irrigated agriculture. The scenario variable water, W(t), is relevant for both segments and covers the general climatic conditions in year t particularly with respect to rainfall and evapotranspiration. It therefore can be used to simulate both short term or cyclical droughts and longer term climate change. Unlike most of the other scenario variables, water will not be set to 1.0 in the starting year, but its initial value will be defined in terms of its position on a nonlinear curve that describes the relationship between water availability and agricultural production. This definition of the initial value depends on the specific climate conditions of the country in the initial year and is to be part of the initialization procedure.

3.6.1 *Rain fed agriculture*

For calculating the impact of the scenario variable 'water' on rain fed agriculture a nonlinear transformation into a water multiplier (WM (t)) is introduced because an increase of one unit water unit does not always have an equal impact on agricultural production. The assumed relationship is derived from the hydrological and agricultural literature and the specific shape of this non-linear relationship greatly depends on local conditions and the kind of crops and/or livestock under consideration. For in-depth applications of PEDA, the definition of this curve requires serious attention. In the current version of PEDA a hypothetical curve has been assumed. Its general features are that in case of serious drought nothing can grow, but after this point small increases in water availability can produce great returns. With further increases in water availability the curve flattens to eventually reaching a saturation level, starting from which more water will adversely affect agricultural outputs. Beyond this point, flooding starts to be harmful to production and may ultimately destroy all production.

The assumed non-linear relationship of water on agricultural outputs only holds if other relevant determinants of soil moisture remain constant over time. Unfortunately, land degradation and land erosion tend to increase the runoff of rainfall and therefore decrease the moisture that will be stored in the soil thus negatively affecting agricultural productivity. Since land degradation is explicitly modeled in other parts of PEDA, the impact of land degradation can be directly taken into account. To do this in quantitative terms, another user defined input parameter has been introduced, i.e. the water impact factor of land degradation or short WIF. WIF is defined in the form of an elasticity applied to current land (defined as R(t) in the previous section). This results in an effective water multiplier (EWM) for rain fed agriculture:

$$EWM(t) = WM(t) * R(t)^{WIF}$$

Values bigger than 1.0 for WIF, increase the effect of the status of the land or resources in the calculation of the effective water multiplier; values smaller than 1.0 decrease its elasticity.

3.6.2 *Irrigated agriculture*

For irrigated agriculture the dynamics in which water availability and irrigation efforts have a joint effect on agricultural outputs are even more complex. The functional relationships defined here are a great simplification but should still be able to capture the most important dynamics. The formula given below creates an intermediate variable, effective irrigation (EIR), which enters the agricultural production function as a multiplier. To determine the value of EIR, PEDA makes a distinction between the situation where water availability is already at or above the saturation level of 1.0 and when it is still below. If the water supply is above the saturation level, efforts in irrigation do not make any difference in agricultural production. If, on the other hand, the water supply is below the saturation level, the positive effect of irrigation efforts further depends on the level of the water supply, and the reservoir capacity effect. The reservoir capacity parameter stands for the potential to stock water for later use in irrigated agriculture.

In the mathematical expression, W(t) stands for the value of the scenario variable water at time t and IR(t) for the value of the irrigation variable. *Frt* is the elasticity of fertilizer in the production function that is applied to irrigation as well because of the lack of better data on the effect of irrigation on agricultural production.

$$EIR(t) = \begin{cases} 1; if\ W(t) \geq 1 \\ \left[RCE * \frac{IR(t)}{IR(0)} * \frac{W(t)}{W(0)} \right]^{Frt} ; if\ W(t) < 1 \end{cases}$$

The second line of the above formula may require some explanation since it is an approximation of several more complex mechanisms. The main reasoning is that even under high irrigation efforts, there needs to be water available in order to have any effect and that even high reservoir capacity does not help if it does not rain for a long time. Ideally, this would require the calculation of cumulative water storage effects over time. A simple approximation is obtained through the multiplication with a ratio of current water over initial water in case that current water availability is still below saturation level. This also implies that if there are no extra irrigation efforts but simply more water, it also generates positive returns in terms of agricultural outputs. This can be interpreted as an additional direct effect of water on production that is weighted by improvements in irrigation and reservoir capacity.

Both effective irrigation (EIR(t)) and the effective water multiplier (EWM(t)) are then added to the agricultural production function as additional multipliers. It is worth noting that in this setup, the two water related variables and current land enter the agricultural production function twice but in two different forms and after transformations as outlined above. The water variable enters both through rain fed and irrigated agriculture as discussed. Land degradation as captured by current land enters as a regular production factor with a given elasticity (as described in the next section) and through the impact of land degradation on increasing runoff and therefore decreasing soil moisture. Depending on the other settings of the model and the specific parameter choice, this indirect effect of land degradation through declining soil moisture may be even more relevant than the direct effect through the production function.

3.7 Agricultural production segment

The total agricultural production in one year, measured in total calories produced (in index form), is calculated through a Cobb-Douglas type agricultural production function. Many agricultural production functions exist, but most of them do not consider the labor force and the skills of the labor force as a production factor. In stead, they largely focus on physical and financial inputs. The chosen production function is a notable exception. Based on pooled data sets of time series for most countries of the world, Hayami and Ruttan (1971) estimated a large number of Cobb-Douglas type production functions with different combinations of input factors for different groups of countries. The equation that seemed most appropriate for PEDA Africa is the Principal Components Regression for developing countries including educational variables. The estimated elasticities are given as default values in PEDA. Should the user have more recent estimates or ones that are more appropriate for the country under consideration, the elasticities should be changed accordingly. In a thorough initialization for a new country, the user should even consider the inclusion of other variables. In that respect, much will depend on the mix of crops under production and the share of livestock in the total outputs.

The total production is a result of the inputs in terms of the human labor force by educational level, land and technological investments in fertilizer use, mechanization, etc. In PEDA, some of these inputs are endogenously determined by the other segments in the model and others are treated in terms of externally defined scenario variables.

The population by age and sex in the eight defined categories affects total agricultural production in two different ways. First, the population projections produce an estimate of the size of the rural labour force. In addition to their technical training (externally defined scenario variable), their productivity is affected by the proportion literates within that category (endogenously determined). The values for all these variables directly enter the agricultural production function as discussed below.

The other chain of causation is a reflection of the vicious cycle reasoning: the factor land is degraded as a function of the relative change in the rural illiterate food insecure segment of the population and of the population density in general as has been discussed above. Other main factors influencing the agricultural output of a country such as mechanization and fertilizer use need to be specified in externally defined scenario variables. As discussed in section 3.6, water is treated in a separate module with an eventual multiplier effect on the total agricultural outputs.

All these inputs to agricultural production are considered on a relative scale, i.e., their values are set to 1.0 in the starting year and change over time as a result of effects emanating from the other segments in the model or as defined in the scenario settings for the exogenous variables. If, for example, we assumed an increase in fertilizer use of 20 percent by 2005, this would mean that the value of that scenario variable is set to increase to 1.2 by that year.

In sum, total agricultural production in terms of total calories produced is calculated in the following multiplicative manner, in which the last two factors are water multipliers that have been discussed earlier:

$$\mathrm{Pr}\,odIndex = LF(t)^{0.534} * R(t)^{0.088} * FERT(t)^{0.162} * MECH(t)^{0.072} * \\ LITLF(t)^{0.276} * TE(t)^{0.158} * EIR(t) * EWM(t)$$

3.8 Food availability and distribution

3.8.1 Food availability

Not all food that is produced in a country will be consumed by its citizens. A fraction will be lost during the harvest, transportation and storage and a part of it may be intended for use as seeds in the next cropping season or for export. On the other hand, imports may complement the food that is produced locally. Mathematically, the net food available (FA) can be expressed in the following manner:

$$FA_t = FP_t * (1 - LT_t) + imports_{t_0} * FIE_t$$

In this expression, the net food production is equal to the gross production (FP) times the proportion that remains after the deduction of the post-harvest losses and seedlings (LT). The post-harvest losses are expressed as a proportion of the total production and can be manipulated in a dynamic scenario variable.

The net food imports are added to the net food production to obtain the net food availability. For the initial year of the projection period an absolute value of imports has to be specified by the user (*imports*) in terms of the daily supply of Kcal per capita. This is usually done as part of the initialization process. FIE is a dynamic scenario variable that has the default value of 1 for the initial year and that allows the user to account for fluctuations in the volume of imports.

3.8.2 Food distribution

After the correction for post-harvest losses and net imports, the estimated amount of available food is distributed over the population in two steps. First an 'urban bias factor' (external scenario variable) determines which fraction of the available food is consumed by the rural and urban population respectively. As with the other scenario variables this is done on a relative scale, with 1.0 reflecting a condition of equality between rural and urban areas in the access to food. A value of 1.1 means that urban areas get 10% more than they would have been attributed if food had been distributed proportionally to the size of the population living in urban areas.

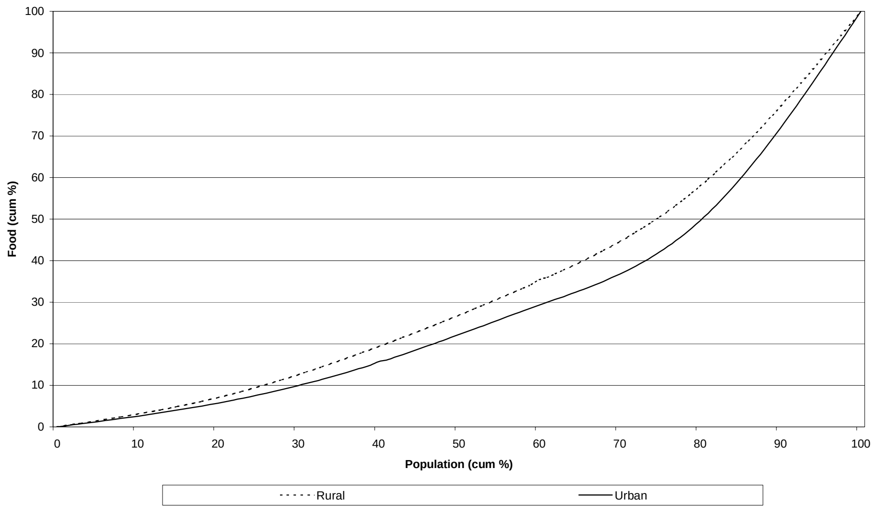
In addition to the urban bias factor, the PEDA model also accounts for the inequality in the access to food within urban and rural areas. The distribution of food is often unequal because some persons simply have more purchasing power than others or have privileged access to food by other means. This will result in the fact that some people remain food insecure even when the average total amount of food reaching the population is theoretically sufficient to provide the necessary minimum diet for everybody. As the access to food is usually more unequal in urban than in rural areas, PEDA works with two food distribution functions, one for rural and one for urban areas.

There is abundant theoretical and empirical evidence indicating that the inequality in the food distribution is at least as important as the total production of food in explaining food insecurity. Especially the work of Amartya Sen (1994) demonstrated that some of the worst famines occurred under conditions in which there would have been enough food for everybody, if the distribution had been appropriate. For this reason it is evident that a model focusing on food security without paying attention to the distributional aspects would be incomplete, if not misleading. The main problem with considering such distributions, however, lies in the fact that hardly any empirical data exist on distributive mechanisms in African countries of today, and that theoretical distributions are hardly appropriate because conditions tend to vary significantly from one country to another. PEDA opts for another solution to approximate the inequality in the access to food through household income distribution functions that exist for a number of African countries on the basis of household expenditure surveys (World Bank, 1997: section 15). Hence, PEDA relies on the assumption that the inequality in the access to food follows a similar distribution than the inequality in the access to income in urban and rural areas respectively.

In each one-year step of the projections, food is allocated to rural and urban areas following the urban bias factor and within each of these areas the food distribution function determines the new sizes of the food secure and insecure sub-populations. Figure 4 gives an example of such a food distribution function. It is a Lorenz Curve with the cumulated proportion of the population on one axis and the cumulated calories available for distribution on the other. The available food is then distributed from right to left along the curve. If the Lorenz curve coincides with a 45°-diagonal, the slope of the curve is equal to 1.0 and everyone in the economy will have access to the mean available calories; i.e. it describes a situation of perfect equality. The convexity of the curve therefore measures the degree of inequality.

The given curve in Figure 3 indicates that in this case, the first (most privileged) 10 per cent of the urban population consume 30 per cent of the available food. Going further down the curve, about half of the urban population consumes more than 75 per cent of the food. The borderline between the food-secure and the food-insecure population is then established by applying an externally defined minimum calorie requirement per person. The iterations are carried out in steps of 1 percent of the population. At the point where the food allocation of the percentile falls below the minimum food requirement specified, the borderline for the proportion of the population that is considered to be food insecure is established. Over time the proportions food insecure may change as a consequence of changes in the population size and food availability, or, possible changes in the assumed food distribution function. In the current version of the PEDA model, however, the food distribution function is assumed to remain constant over the whole projection period. Defining the food distribution functions for rural and urban areas is part of process of initializing the model for a new country.

Figure 3: the food distribution function for urban and rural areas



3.9 HIV/AIDS in PEDA

As a model demonstrating the interactions between population, education, environment and food security, PEDA has initially not been designed to explicitly cover the possible sustainable development and food security consequences of HIV/AIDS. However, since the pandemic has become such a challenge to many African countries and because it is not meaningful to talk about the future development path without explicitly considering HIV/AIDS, this section will discuss the way in which HIV/AIDS is incorporated in PEDA. As there is still relatively little empirical knowledge on the trends of the pandemic and especially not on its effect on the different sectors on the economy, the model is necessarily experimental in its conception and treatment of HIV/AIDS.

The most obvious impact of HIV/AIDS on the nexus is through excess mortality and thus indirectly through a reduction of the labour force. As the age pattern of AIDS mortality differs from the one observed in a population without AIDS, it was opted to include that effect via a user specified scenario variable. In that scenario variable the user needs to specify AIDS related morbidity rates, which is similar to prevalence information but with lower values than the widely available HIV prevalence rates. The morbidity rates are translated into age specific mortality rates, which are added to the age specific mortality pattern of each of the eight different subgroups in the population. The additional age specific mortality pattern due to AIDS has been estimated on the basis of a model for Botswana (Sanderson, forthcoming). AIDS mortality has a typical shape with very high rates in the early adulthood, and due to vertical transmission also in early childhood. The specified age specific excess mortality due to AIDS is then scaled up or down depending on the morbidity level set by the user in the HIV/AIDS scenario variable and superimposed to the mortality from other causes. If a user wants to specify age specific excess mortality on the basis of country specific data, this has to be implemented during the process of initialization.

The user should be aware that one can not account for the demographic impact through manipulation of this scenario variable alone since it only changes the age pattern of mortality but not the level. A consistent scenario should therefore include setting lower life expectancies than one would have assumed in the absence of AIDS, and the development of life expectancy over time will have to be set in such a way that it reflects the recent and anticipated future trend of HIV prevalence and the resulting AIDS mortality under the assumed absence of efficient medication.

In the current version of PEDA, the scenario variable wherein the user specifies the AIDS morbidity rates is applicable to the population as a whole. As of now, different mortality rates (as implied by different morbidity rates) cannot be applied to the eight sub groups separately. However, the user can make different assumptions regarding the expected reduction in the level of life expectancy and thus account for a potential different impact of HIV/AIDS in rural and urban areas, among literates and illiterates etc.

HIV/AIDS not only induces increased mortality with its impact on the population structure; it also seriously affects agricultural production through different mechanisms. Most of these effects are not endogenized in PEDA and need to be dealt with in the form of consistent user-defined scenarios. The user of PEDA has to choose the various model parameters and scenario variables in such a way that they describe consistent “stories” or scenarios of possible future trends.

If AIDS is assumed to be a major issue in a country, then AIDS mortality and morbidity should be assumed to reduce the educational enrollment and technical education due to AIDS orphanhood, fewer qualified teachers (they may die) and AIDS-induced financial and economic constraints. These likely negative consequences of AIDS on the incomes of affected households may also reduce investments in fertilizer, irrigation and mechanical inputs in agriculture. The only endogenized feedback from the AIDS morbidity rates, as set by the user, on agricultural production is the reduction in the productivity of the labor force. By default the model assumes a linear decline in the productivity of the labor force at a rate of the morbidity level. Put more simply, people who are sick, i.e. symptomatic with HIV/AIDS are subtracted from the labor force. The rationale is that the capacity of sick people to work is greatly reduced and that some healthy people will have to look after their sick relatives instead of working and thus reduce their productivity in agriculture.

Taken together these different effects may have a drastic impact on agricultural outputs and the development of a country, but at the moment, hardly any systematic empirical evidence exists on these issues. Hence, the assumptions need to be highly speculative at this point. If more empirical information on these effects becomes available in the future, then PEDA could be expanded into a model that quite comprehensively captures the impacts of AIDS on human development and food security.

4 PEDA projections for Ethiopia

To date, the PEDA model has been initialized for 9 African countries. The initialization for Ethiopia goes furthest in terms of the customization to country specific conditions. In considering the outcomes of these PEDA projections one must nevertheless be aware that this customization is not exhaustive. To estimate agricultural outputs, for example, the model mainly relies on a generic agricultural production function for Africa. Consequently the projection results are to be seen as indicative and could still be improved upon. Aspects of the current application of PEDA for Ethiopia that are subject for revision include the definition of the food distribution function, the elasticities of the agricultural production function, the water saturation curve, and the parameters of the land module.

Before discussing the projection results for Ethiopia, we first give a descriptive overview of the situation in the country with regard to the nexus issues and the policy responses.

4.1 The Ethiopian population-environment-agriculture nexus: beyond the threshold of a sustainable livelihood ?

Over the last couple of decades Ethiopia has been the subject of many headlines reporting recurrent war and famine. Although the latter is often caused by factors that cannot be modeled by PEDA, the model is capable of illustrating the fragile equilibrium between population growth, environmental stress and the performance of the agricultural sector that serves as the context wherein these tragedies take place. In these situations, it are often only slight disturbances caused by a period of reduced rainfall or isolation resulting from conflicts or a malfunctioning distribution system that lead to acute food security problems. In the case of Ethiopia, they have occasionally grown to catastrophic proportions.

Speaking of an equilibrium when describing the population-environment-agriculture nexus in Ethiopia is, however, optimistic. The country is facing structural problems in all three sectors, and they are often reinforcing each other. The scope of the problem is captured in the fact that about 50 to 60 per cent of the population is considered to be chronically food insecure (Befekadu & Berhanu, 2000: 176). More than half of the Ethiopian children under the age of five are stunted and more than one in four severely stunted. Eleven percent is moderately wasted and one percent is severely wasted. (CSA/Macro International, 2000: 17).

Like many African countries, Ethiopia's population is growing fast. It is only since the early 1990s that fertility started declining from rates above 7.5 on the national level. Combined with slight improvements in the control of mortality since the 1960s, it is responsible for population growth rates of up to 3 per cent annually. Around 85 per cent of the estimated 65 million inhabitants live in rural areas, most of them concentrated in the northern and central highlands (CSA, 1999).

According to the official national medium variant population projections, the population will more than double by the year 2030, implying an average growth rate of around 2.4 per cent (CSA, 1999: 343). Even under this ‘favorable’ scenario that assumes a steep decline in fertility to 3.32 by 2030, population growth will continue to exert serious pressure on the environment and will remain an enormous challenge to agriculture.

Although these data are usually difficult to get hold of, the fragmentary information presented below suggest that environmental degradation, whether it be through deforestation, soil erosion or the depletion of soil nutrients, will be one of the major constraints in making up a sustainable livelihood for most of those living in rural areas. Over the last century, the land covered by forests has gone down from approximately 40 to 3 percent[1]. In the early 1990s, the annual rate of deforestation was estimated at 88,000ha per year while the rate at which this loss is being replaced through afforestation is estimated

[1] Other sources are somewhat more optimistic, reporting that in 1995 around 6.9 percent of the 1.11 millions km² land area was covered by forests and woodland (UNDP, 1998: 69).

at 6,000ha a year (TGE-OPM, 1993: 7). The causes are related to the expansion of settlements and agriculture, and the use of fuel wood as a primary source of energy. One estimate regarding soil erosion states that by 2010, 18 per cent of the highlands will not be suitable for sustained farming. In addition to the cropping pattern and techniques, the nature of the terrain and the intensity of rainfall in peak periods are two important factors that contribute to soil erosion. About one third of the highlands has a slope exceeding 30 per cent, making it susceptible to soil erosion once the vegetation is removed. In addition, land degradation is exacerbated by centuries of crop production without fertilizer use or any other investment in land conservation. Crop residues are used for feeding cattle and animal manure is used for fuel instead of putting it back on the land. Not surprisingly, these practices have resulted in the net outflow of vital nutrients, and the reduction of the soil's capacity for moisture retention (Befekadu & Berhanu, 2000: 180).

The situation described above is particularly worrying since the agriculture is, and will remain for a long time the mainstay of the Ethiopian economy. The share of agriculture in the country's GDP is around 51 percent (Befekadu & Berhanu, 2000: 155), it provides employment for 85 percent of the population, it generates up to 90 percent of the export earnings and it is also the main supplier of raw materials for the manufacturing sector (Dejene, 2000: 13). Regardless of its prominent position in the Ethiopian economy, the prospects for the performance of the agricultural sector are not bright at all. In addition to the environmental problems, farmers face numerous constraints related to diminishing farm sizes, low tenure security, imperfect agricultural markets (partly due to a lack of infrastructure), and a weak agricultural research base and extension system (Befekadu & Berhanu, 2000: 177-195). Many of these constraints act together, condemning farmers to subsistence agriculture, and consequently limiting investments in land and exacerbating land degradation.

Agricultural land in Ethiopia is managed on the communal level and farmers do not have the right of private ownership. Throughout history, agricultural land has been redistributed frequently, thereby often reducing farm sizes. The need to accommodate an increasing population has required many local authorities, particularly in the northern highlands, to distribute grazing land for farming, thereby seriously reducing the already insufficient animal fodder (Befekadu & Berhanu, 2000: 199).

The average farm size on the national level is 1 ha per household, but 62 percent of the households cultivate less than that. On these small plots, subsistence and survival agriculture is the primary concern. All income, both from farm and non-farm activities, is invested in food. There simply is no surplus for investment in land conservation or agricultural intensification (Befekadu & Berhanu, 2000: 178-179). In the mid 1990s, only 4.6 percent of the arable land was irrigated (UNDP, 1998: 69), less than 2 per cent of the farmers were reported to use improved seeds (Befekadu & Berhanu, 2000: 184), and fertilizer use is situated around 7 kg of nutrient per hectare of arable land compared to an average of 9 kg for Sub-Saharan Africa and 65 kg for the world. (Dejene, 2000: 14). These limited technological inputs, make agricultural production very susceptible to fluctuations in rainfall.

In addition to all other constraints, many farmers have little incentive to produce an agricultural surplus, since markets to sell their goods are inaccessible. Around three quarters of the farms are more than half a day walk from an all-weather road. Farmers' produce must be carried long distances by pack animals or by humans to a location where buyers are found (Befekadu & Berhanu, 2000: 189).

Although disturbed by recurrent conflict and war over the last decades, the per capita agricultural production, on average declined, at a dramatic rate of 1.15 percent a year between 1970 and 2000. Over the last decade the per capita food production has declined at a somewhat slower pace of 0.64 percent per year (FAO/WFP, 2001: 3). Considered in isolation, these figures are definitely in support of a Malthusian disaster scenario. However, improved economic management, currency and trade liberalization, and grain and agricultural input liberalization are considered to be important factors that contributed to an average economic growth of 6.5 per cent while inflation was kept under 4 percent between 1993 and 1998. A period of favorable rainfall in the mid 1990s definitely added to this impressive growth in GDP, but once again, war, a multiyear drought and also the increased burden of HIV/AIDS virtually stalled economic growth in the last two years (FAO/WFP, 2001: 3).

The fast economic growth rates observed in the mid 1990s definitely indicate that a doom scenario of declining per capita production, increasing poverty and food insecurity is not inevitable, but it needs, as will be illustrated by the PEDA simulations, a concerted and sustained effort in multiple sectors of the society and economy.

4.2 The policy response

The Ethiopian Government is aware of the challenges posed by the negative interactions between demographic, environmental and agricultural variables. In 1993, just after the downfall of the military socialist regime, it recognizes that "… demographic and developmental factors reinforce each other. High fertility and rapid population growth exert negative influences on economic and social development and low levels of economic and social development provide the climate favouring high fertility and hence rapid population growth. Because of an unholy combination of these forces, Ethiopia finds herself in a vicious circle of failure and defeatism" (TGE-OPM, 1993: 24-25). To tackle these problems, the government committed itself to holistic planning and even established a multidisciplinary office within the Office of the Prime Minister and a National Population Council that is to be composed of members from various ministries.

Among the general objectives of the National Population Policy are (TGE-OPM, 1993: 24-25):

- closing the gap between high population growth (TFR of 4.0 by 2015) and low economic productivity through planned reduction of population growth and increasing economic returns;
- reducing the rate of rural-urban migration
- maintaining and improving the carrying capacity of the environment
- raising the economic and social status of women and other vulnerable groups

The current agricultural development strategy of the government is known as Agricultural Development Led Industrialization (ADLI). This strategy gives high priority to smallholder farmers in terms of provision of incentive packages and technologies for increased agricultural productivity. (Dejene, 2000: 13). As a result, fertilizer use has increased in the last couple of years, but because of high prices (due to the removal of subsidies in 1997) and a poor distribution and credit system, still 40% of the fertilizer made available remained unsold in 1996-1997 (Befekadu & Berhanu, 2000:192). Fertilizers use well below the planned quantity, remains a constraint to agricultural intensification up to the present moment (FAO/WFP, 2001: 8).

In 1997, the Ethiopian government also approved an environmental policy that is cross-sectoral, integrative, supports decentralized initiatives, and that proposes a legislative framework and a monitoring and evaluation system (Dejene, 2000: 23-24).

The Ethiopian Government is thus clearly aware of the vicious circle of increasing poverty, environmental degradation and decreasing agricultural outputs. It has developed policies to break out of it, and even made institutional reforms to support them. However, relatively little quantitative objectives have been formulated, and evidence of the performance of the agricultural sector and economy do not give a clear indication that the implementation of these policies will be sufficient to revert the current negative development path.

4.3 PEDA applied to Ethiopia

In preparing the baseline data for Ethiopia and a baseline scenario for making projections, we have relied for as far as possible, on observed data for the country, and on time-series and linearly extended them into the future. However, some data are simply not available or very difficult to get hold of. In these cases, we have made estimates; usually on the optimistic side.

4.4 The baseline data and the baseline scenario for PEDA Ethiopia

4.4.1 The demographic baseline data

The total population by single years of age and sex as well as the age specific fertility and mortality schedules for each of the eight states have been prepared following the procedures illustrated in the PEDA Technical Manual (UNECA, forthcoming). The data come from the 1994 Population and Housing Census (CSA, 1999). Since disaggregated information on fertility and mortality for each of the eight states is not always available, some estimation procedures had to be followed. In making these estimates, it was always verified that the disaggregated values were consistent with the observed or reported aggregated figures.

4.4.2 The food distribution curve

The food distribution functions for urban and rural areas are prepared following the procedures illustrated in the PEDA Technical Manual, this time using household expenditure data published by the World Bank (1997). At the time of the initialization of PEDA for Ethiopia, no household expenditure data were available. Therefore, we used data for Uganda as a proxy. Together with the food availability in a country, the food distribution curves are very important in determining the proportion of the population that will be food insecure. In our case, the estimate of the share of the population that is food insecure for the initial year of the projections is around 65 percent, thus somewhat higher than the figures often cited for Ethiopia.

4.4.3 General settings and model parameters

These are parameters that apply to the country as a whole and deal with beginning and end of the projection period, the food production and imports in the initial year, the parameters of the land module, and the rural-urban migration parameter. Their values for the PEDA Ethiopia projections are specified in Table 1.

Table 1: General settings and model parameters

Parameter	Value	Comments
Initial year	1995	
End of the projection period	2030	To present the long-term dynamics, the projections are sometimes extended to 2050. The fertility and life expectancy assumptions (cfr. infra) are in these cases assumed to remain constant after 2030.
Production (and imports) of Kcal per capita in the initial year	1756.8	This figure refers to the net daily per capita production in the initial year. In addition to the production, the model also accounts for the net imports to calculate the net food availability in the initial year. On the ANDI web site, 1830 is reported as the average (net) supply of Kcal per capita for the period 1995-1997. Although other sources report lower figures for the daily per capita supply in 1995 (e.g. 1750 in UNDP, 1998: 68 and 1727 in the FAOSTAT database), we have chosen to use the most optimistic figure. Between 1980 and 1998, food imports accounted on average for 11.8% of the gross available food, with extremes falling as low as 4.8% and as high as 18.3% (Dejene, 2000:17). Depending on the sources used, the data on the food imports (including food aid) vary greatly. Dejene (2000: 17) reports the share of net food imports for the year 1994/1995 as 14 percent. In the FAO food balance sheets, (net) food imports in 1995 accounted for only 4 percent of the total available food for consumption (FAOSTAT web site). Given our philosophy to present an optimistic baseline scenario for the food security situation, we will assume that only 4 percent of the total food supply in 1995 was imported. The 4 percent of net food imports stood for around 620,000 tons of food. WFP reports that for 1995 652,000 tons of food was delivered to Ethiopia as food aid alone (WFP web site). Our estimates of food deficits and imports are therefore likely to be on the conservative side.
Assumed minimum consumption of daily kcal per capita in order to be food secure	1700	Values with respect to the minimum and desirable daily per capita energy intake for Ethiopia vary between 1700 and 2100 kcal. The former was used as a threshold below which relief aid was distributed. 2100 kcal is the nationally recommended minimum (Dejene, 2000: 15).
Land degradation impact factor, γ	0.03	Since no reliable empirical information is available with respect to the impact of population pressure on land resources, estimates of the respective parameters were made that would result in an expansion of the productivity of land resources of 1.9 percent by 2005. Again, this is a rather optimistic scenario since the possibilities for land expansion under rain-fed agriculture are not very high and that new land brought under cultivation may be offset or even outstripped by land degradation (Befekadu & Berhanu, 2000: 146). The values of the parameters of the land module in the baseline scenario for PEDA-Ethiopia are gamma=0.03, eta= 4, a=0.0175.
Proportion of cohort moving to cities	0.06	In the census of 1994, 4 percent of the population reported to have moved from rural to urban areas over their lifetime (CSA, 1999: 196). In the case of PEDA-Ethiopia, we have chosen for a slightly higher figure in the baseline scenario. Given the lower fertility rates in urban areas, this scenario would more or less result in a status quo of the proportion living in rural and urban areas.

4.4.4 Sub-population parameters

The TFR and life expectancy values for each of the eight states have been estimated following the procedures described in the PEDA Technical Manual. This is done in such a way that the nested values are consistent with the aggregated values reported in the census monograph (CSA, 1999). Under the baseline scenario we make similar assumptions as those made by the Central Statistical Authority for their medium variant population projections. These include a steep decline in fertility and an important increase in life expectancy (see Table 3 for more details).

According to the 1994 census (CSA, 1999: 85) only 23.3 per cent of the population was considered literate[2]. As is illustrated in Table 2, the discrepancies between males and females, and especially between urban and rural areas are considerable. Under the baseline scenario (see Table 3), we assume

[2] This figure is much lower than the 35 percent reported by UNESCO for 1995 (UNESCO web site).

not only that enrollment rates will increase rapidly, but also that the gender gap will be significantly reduced. In urban areas we assume that 95 percent of all children will make the transition from illiterate to literate status. In rural areas, we assume that 60 percent of the boys and 55 percent of the girls will enter school and become literate. Since education is treated statically in the PEDA model, these transition rates will be applied from the first year of the projection period. Again, these are very optimistic scenario assumptions as the gross enrollment rates increased by only 25 and 20 percentage points for boys and girls respectively between 1970 and 1996 (UNESCO web site).

Table 2: a description of the fertility, mortality and literacy conditions in 1995

	TFR	E_0		Percentage literate	
		Males	Females	Males	Females
St1: Urban, Literate, Food Secure	4.28	60.4	64.7		
St2: Urban, Literate, Food Insecure	4.28	55.8	59.8		
St3: Urban, Illiterate, Food Secure	4.83	53.5	57.5	77.4	60.6
St4: Urban, Illiterate, Food Insecure	4.83	49.4	53.8	77.4	60.6
St5: Rural, Literate, Food Secure	5.97	56.6	59.5		
St6: Rural, Literate, Food Insecure	6.86	52.4	55.1		
St7: Rural, Illiterate, Food Secure	6.73	50.3	53.0	21.8	8.6
St8: Rural, Illiterate, Food Insecure	7.74	46.6	49.0	21.8	8.6
Aggregate	6.74	50.0	51.6		

Table 3: fertility, mortality and literacy assumptions under the baseline scenario (by 2030)

	TFR	E_0		Educational transition rates	
		Males	Females	Males	Females
St1: Urban, Literate, Food Secure	2.28	79.9	84.8		
St2: Urban, Literate, Food Insecure	2.28	73.7	78.4		
St3: Urban, Illiterate, Food Secure	2.58	70.8	75.4	95.0	95.0
St4: Urban, Illiterate, Food Insecure	2.58	65.3	69.7	95.0	95.0
St5: Rural, Literate, Food Secure	3.18	74.8	78.0		
St6: Rural, Literate, Food Insecure	3.66	69.3	72.2		
St7: Rural, Illiterate, Food Secure	3.59	66.5	69.4	60.0	55.0
St8: Rural, Illiterate, Food Insecure	4.13	61.6	64.2	60.0	55.0
Aggregate	3.51	65.0	68.0		

4.4.5 HIV/AIDS

The first cases of AIDS in Ethiopia were reported in the mid eighties. By 1989 the adult HIV prevalence rate (ages 15 and older) was estimated around 1 percent. In the 1990s, prevalence rates grew fast to attain 3.2 percent in 1993 and 7.4 percent in 1997. Large discrepancies -still- exist between rural and urban areas. In the former, the adult prevalence rate was believed to be around 4.5 percent in 1997, and for urban areas around 17 percent (MoH, 1998: 5). Conservative official estimates are that prevalence rates will increase to 9 percent by 2006 and would stabilize at that level (MoH, 1998: 16).

Reporting on the prevalence between the ages 15-49[3], the UNAIDS estimate for the end of 1997 was 9.3 percent (UNAIDS, 1998:3). By the end of 1999, that figure had increased to 10.6 percent. This means that around 3 million adults and children are living with HIV/AIDS in Ethiopia. In 1999 alone, around 280,000 people would have died from AIDS related illnesses (UNAIDS, 2000: 3).

For several technical reasons, PEDA works with HIV/AIDS morbidity rates. Because the symptomatic period (1-3 years) is much shorter than the incubation period (5-10 years), morbidity rates tend to be less than a third of the adult (15-49) prevalence rates. Given an estimate of a prevalence rate of 5.5

[3] This is the new standardized definition of adult HIV prevalence adopted by UNAIDS. The values are usually higher than for the 15+ definition. Based on the data reported for 1997 by the Ministry of Health (MoH, old definition) and UNAIDS (new definition), we assume that the prevalence rates of the population aged 15-49 is 1.5 percent higher than that of the population of 15 years and older.

percent for the population aged 15-49 in 1995, we would reach a morbidity rate of 1.1 if we consider the morbidity rate to be one fifth of the prevalence rate. This value is used as an input to reflect the conditions in the initial year of the projections.

In the baseline scenario, this HIV/AIDS morbidity level is assumed to remain constant. Because only relative increases in the HIV/AIDS morbidity levels from one year to another are used to calculate a reduction in the productivity of the labour force, the impact of HIV/AIDS in the baseline scenario is therefore assumed to remain constant at the 1995 level as well. Note that the purely demographic impact of HIV/AIDS through excess mortality is mainly manipulated by setting the life expectancy levels (see UNECA, forthcoming, for more details on the treatment of HIV/AIDS in PEDA). It must be stressed that these are -unrealistically- optimistic baseline scenario assumptions.

4.4.6 *Other scenario variables affecting food production and supply*

Net food imports

For the initial year the net food imports were determined to be 4 percent of the domestically produced food or 620,000 tons (cfr. supra). Under the baseline scenario we assume that food imports will increase by 2 percent a year, reaching a level of approximately 1,240,000 tons annually by the year 2030.

Post harvest losses

The agricultural production function in PEDA calculates the gross agricultural production. To determine the net food supply to the population, assumptions need to be made about post harvest losses and net imports. The post harvest losses, -including the deduction of the produce that is used as seeds for the next season- in Ethiopia are estimated at 15 percent of the production (Dejene, 2000: 17). Although these figures may be even higher in years of good yields because the on-farm storage capacity is limited and crop protection chemicals are not available (FAO/WFP, 1996:2), the baseline scenario assumes a slight reduction of post harvest losses of 1 percent a year.

Water

For the initial year data, the user has to determine how favourable water conditions were for agriculture, i.e. the position on the water saturation curve. To do so, we relied on rainfall time series during the two main cropping seasons (*'belg'* and *'meher'*) for the period 1992-1999 (Tucker, 2000), and on food production assessments in the same period. In FAO/WFP, reports the year 1996 (harvest 1996-1997) is considered to be exceptionally good, "a bumper crop" (FAO/WFP, 1996). The value of water scenario variable for the year 1996 is thus set to be equal to 1, i.e. the figure describing optimal water conditions for agricultural production. Once the optimal value of rainfall for agriculture is determined, the values of the water scenario value can be determined accordingly. For the baseline scenario, the observed rainfall pattern during the cropping seasons is used for the period 1995-1999. From the year 2000 onwards, the observed rainfall pattern for 1992-1999 is repeated. Since that period was characterised by relatively favourable rainfall conditions, the baseline water scenario settings are again of an optimistic nature.

Irrigation

The share of irrigated agriculture in Ethiopia is very low. According to UNDP (1998), only 4.5 percent of the arable land (or 23,000 km²) is irrigated. In the FAOSTAT database, no significant increase in irrigated land is recorded since 1993. Under the baseline scenario, we nevertheless assume an annual increase in irrigated land of 1 percent.

Fertilizer use

Following efforts of the current government to expand the National Extension Programme, fertilizer use in the mid 1990s increased rapidly at times but its application fluctuates a lot. From one year to another fertilizer use increased by 5 percent in 1996 (FAO/WFP, 1996), decreased by 20 percent in 1997 (FAO/WFP, 1997), increased by 27 percent in 1998 (FAO/WFP, 1998) and increased by 2.6 percent in 1999 (FAO/WFP, 2000). The important reduction in fertilizer use in 1997 was caused by the removal of subsidies and credit restrictions. It is thus difficult to forecast how future fertilizer use will evolve. In the baseline scenario, we assume a steady increase in fertilizer use of 5 percent a year. If only 7kg of nutrients per ha or arable land were used in 1995, this means it would increase to almost 40kg by 2030.

Machinery use

Little data are available on machinery use in the Ethiopian agriculture. Due to the small plot size, the abundance of manual labour and the relatively high cost of machinery, it is virtually non-existent outside commercial or state farms. According to the FAOSTAT database, only 3,000 tractors were in use in the early 1990s and this figure would not have changed since. In the baseline scenario, we assume that machinery use will increase by 0.5 percent a year.

Technical education of the workforce

In addition to the literacy of the labour force, the agricultural production function also takes the technical education of the workforce into account. This covers a variety of skills directly related to agricultural production techniques and may be improved through governmental extension services and activities of NGO's. It is, however, difficult to obtain empirical data on this issue. A project of the 1980s known as the Peasant Agricultural Development Program (PADEP) that included a training and visit approach, is not considered a big success. A new system of agricultural extension, known as the Participatory Demonstration and Training Extension System (PADETTES) was launched by the current government in 1994/95. The system includes a training component and the application of a package of fertilizer, improved seeds and pesticides. The objective for the 1997/98-season was to reach 2.9 million participants. Although the government has given the program high priority, is not very clear whether the objectives have been reached. Problems faced in the implementation of the programme are related to the increasing prices of these packages following the removal of subsidies in 1997, the limited financial capacity of farmers, decreasing farm sizes, and also the required moisture level for the seeds and fertilizers to generate an improved production. They thus increase the risk of failure under high rainfall variability as is the case in most part of the country (Befekadu & Berhanu, 2000: 185-186).

The baseline scenario assumes that the level of technical education of the agricultural labour force will increase at an annual rate of 1.5 percent.

Urban bias factor

In the baseline scenario, we do not assume any urban or rural bias. Food is distributed proportionally to the quantity of people living in rural and urban areas.

4.4.7 Other adjustments made to the default settings of PEDA for the application to Ethiopia

Other adjustments made to the default settings of the PEDA model in the application to Ethiopia are the reduction of the elasticity of the size of the labour force in the agricultural production function and the manipulation of the water saturation curve.

Depending on the amount and timing of the rainfall, agricultural production in Ethiopia can easily go up or down with 20 to 30 per cent. The default water saturation curve was not able to capture this responsiveness of the agricultural outputs to the fluctuations in the rainfall pattern. The water saturation curve was therefore changed to make the agricultural production much more of a linear function of the quantity of rainfall. Note that a different shape of the water saturation curve may strongly influence the year-to-year fluctuations in agricultural outputs, but it does not really influence the medium to long-term pattern dynamics that much.

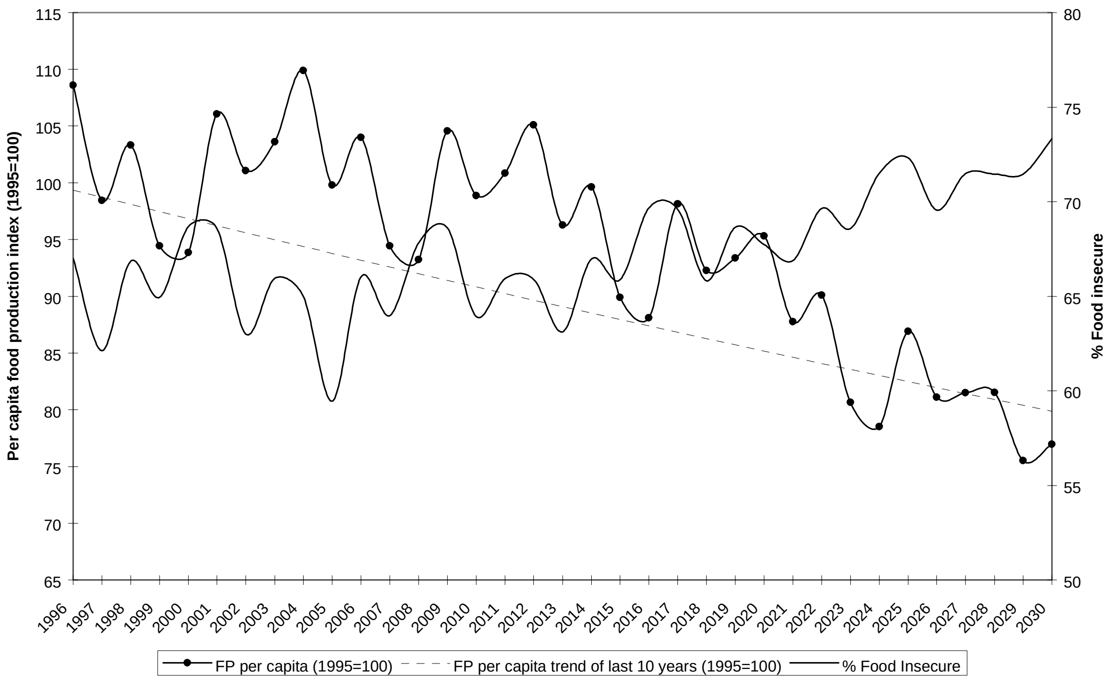
The agricultural production function that is by default used in PEDA attributes a relatively big elasticity of the growth of the rural labour force on agricultural outputs. Such an agricultural production function would be suitable to describe a situation where a growing population could move into previously unused land to increase production. However, as has been argued earlier, the potential for cropland expansion is very limited in Ethiopia and a growing workforce would not necessarily result in increased production. We therefore reduced the elasticity of labour in the agricultural production function from 0.534 to 0.2, thereby giving the general educational level of the population more weight than the size of the workforce itself.

4.5 Simulation results for the baseline scenario

While presenting the assumptions for the baseline scenario, we mentioned that we have chosen for rather optimistic values. The moment has now come to verify whether the projection results are equally optimistic. The answer is ambivalent. As mentioned earlier in this paper, per capita food production in Ethiopia declined in the 1990s on average by 0.64 percent a year. For illustrative purposes, this linear trend is extended in Figure 4 throughout the projection period. Not considering the year-by-year variations in per capita production that are caused by fluctuations in rainfall, our projections for the next 25 years present indeed a slightly more positive image. Nevertheless, the overall tendency of per capita agricultural production continues to decline at an alarming rate. Even under all good conditions elaborated upon above, the per capita agricultural production by the end of the projection period will be less than 80 percent of what it was in 1995. In that sense the prospects under our optimistic baseline scenario are still very poor.

Similarly, the proportion food insecure is expected to increase over the projection period by almost 10 percent. In addition to the food production and population growth, this output variable also reflects changes in post-harvest losses and changes in the net import of food. Our positive assumptions with this regard are not capable of solving the food security problem in the country either. It seems indeed as if the population-environment-agriculture nexus in Ethiopia has fallen below the threshold of sustainability. To give one more example: under the conditions summarized in the baseline scenario, it is estimated that the food imports will have to increase by more than 7 percent annually in order to stabilize the proportion of food insecure people in the country. This figure is almost three times higher than the current population growth rate.

Figure 4: the evolution of the per capita food production and the % food insecure under the baseline scenario



Underlying this negative tendency in per capita food production is the degradation of the natural resources stock. PEDA assumes that a fast growing population contributes to increasing land degradation, and land is precisely one of the important production factors. Particularly the rural illiterate and food insecure segment of the population is expected to deplete natural resources in their quest for survival. In our projections the total population is expected to double by 2030, and despite all our assumptions regarding the improvement in the literacy rates, a decreasing fertility and the increased inputs in agriculture, the rural food insecure segment of the population is expected to grow fastest (more than double by 2030). As a result, the land stock is estimated to maintain only 86 percent of its productive capacity by the year 2030 (see Table 5).

4.6 Other scenarios: HIV/AIDS, drought and migration

Lets now turn to a less optimistic scenario; one where HIV/AIDS is playing a more prominent role. To ease our task, we will assume that HIV prevalence rates will be similar in rural and urban areas, and to correct for the overestimation of the prevalence in rural areas, we will use a relatively conservative estimate of the evolution of the pandemic in Ethiopia. We assume that AIDS morbidity levels will rapidly increase in the second half of the 1990s to reach 2 percent by the year 2000 (this stands for an adult HIV prevalence rate of around 10 percent). After that, morbidity levels will pend around 2.15 percent for the next decade and then start declining gradually. Life expectancy assumptions have been modified to be around 10 years lower by the year 2030 compared to a situation without AIDS.

Although, there exist a number of studies that point at the socio-economic impact of HIV/AIDS (see for example Stover & Bollinger, 1999 and Bollinger et al., 1999), none of them arrive at quantifying the nation-wide impact of HIV/AIDS on the different sectors of the economy and human development. Most of the effects reported result in the reduction of the labour force, through excess mortality and morbidity, and a reduction of the household income. The latter is often an outcome of the reduction of the labour force itself, and the costs for medical treatment and funeral services. These two effects have many spin-offs. A reduction of the labour force means that it has to be compensated for by other family members (often children that are withdrawn from school), or that it leads to reduced labour inputs in agriculture. A reduction of the household income induces farmers to economize on the technological inputs in agriculture and land preservation, and even on the education of their children. Other often mentioned side effects of the HIV/AIDS pandemic are the cutback in qualified personnel such as teachers, and the reduction of the transfer of skills from one generation to another. The arguments summarized here justify the scenario assumptions presented in Table 4, though their values remain relatively arbitrary because of a lack of more precise empirical information.

For illustrative purposes, we have defined two other alternative scenarios in addition to the HIV/AIDS scenario. One scenario assumes two three-year periods of reduced rainfall and the second incorporates a higher rate of rural-urban migration. For these two scenarios, all the other assumptions are similar to the one of the baseline scenario (see Table 4).

Table 4: a comparison of the scenario assumptions of the baseline and HIV/AIDS scenario

Indicator	Scenario			
	Baseline	*HIV/AIDS*	*Drought*	*Migration*
HIV/AIDS morbidity	Constant at 1.1%	Peak at 2.18% in 2010	*	*
Life expectancy	See Table 3	Reduction of 10 years by 2030 as compared to the scenario without HIV/AIDS	*	*
Urban literacy transition rates	95% for males 95% for females	90% for males 85% for females	*	*
Rural literacy transition rates	60% for males 55% for females	40% for males 35% for females	*	*
Increase in the technical education of the labour force	1.5% annually	0.9% annually	*	*
Reduction in Post harvest losses	1% annually	0.75 % annually	*	*
Increase in fertilizer use	5% annually	4% annually	*	*
Increase in machinery use	0.5% annually	0.4% annually	*	*
Increase in irrigation	1% annually	0.75% annually	*	*
Land regeneration parameter (a)	0.0175	0.015	*	*
Water	Values based on rainfall time series for the period 1992-1999	*	Two three year periods of reduced rainfall (value 0.7 for the water scenario variable)	*
Rural-urban migration	6% of each rural cohort migrates	*	*	25% or each rural cohort migrates

* same assumptions as under the baseline scenario

As could be expected, the prospects under the AIDS scenario are even worse than under the baseline scenario. In addition to the important human impact, the per capita food production will drop to less than three fourths of what it was in 1995. As a result, the share of the food insecure segment will increase to more than 75 percent of the population by 2030 (Table 5). If our assumptions on the effect of the AIDS pandemic are correct, it will have a devastating effect on both the food security situation in the country and a number of other human development related variables. Although mostly a direct result of our scenario assumptions, both life expectancy and literate life expectancy (LLE)[4] of the population is expected to be much lower than under the baseline scenario.

[4] Number of years a person is expected to live in a literate status from the age of 15 onwards. See UNECA (forthcoming) for more details on this output variable).

Table 5: projection results for the baseline and alternative scenarios

Indicator	Year	Scenario			
		Baseline	*HIV/AIDS*	*Drought*	*Migration*
Total population (in millions)	2030	132.8	119.9	133.0	130.3
	2050	195.3	164.7	195.7	186.8
% Food Insecure	2030	73.3	76.2	75.2	72.5
	2050	92.8	98.0	98.0	83.3
Life expectancy	2030	66.5	56.0	66.4	67.0
	2050	65.8	55.0	65.6	67.1
TFR	2030	3.5	3.6	3.5	3.3
	2050	3.6	3.7	3.6	3.3
LLE (age 15+)	2030	19.9	13.6	19.9	20.7
	2050	23.4	14.5	23.3	25.6
Land (R(t))	2030	0.86	0.84	0.85	0.9
	2050	0.49	0.51	0.48	0.61

The projections for the other two scenarios also have results worthwhile mentioning. Apart from the acute food security problems that arise during periods of reduced rainfall, drought has a long-term negative effect on the population-environment agricultural nexus that extends the period of the drought itself. This is for example illustrated in the value of the natural resources stock at the end of the projection period which is lower than under the baseline scenario and a higher proportion of the population that is food insecure (see Table 5). The migration scenario, on the other hand, has perhaps unexpected positive results. Its gains are visible both in terms of the food security status of the population and in terms of the human development component. Increased migration facilitates a fertility decline, an increase in life expectancy and literate life expectancy, and also relieves the pressure on the natural resources stock. As suggested by PEDA, rural-urban migration should thus be considered as part of a policy strategy to tackle the food security problem in the country. Currently, the Government of Ethiopia considers internal migration as a problem rather than part of the solution to their development problems (cfr. supra). Increased rural-urban migration, of course, adds to the challenge of creating jobs for the migrants and with already high urban unemployment rates, this is not self-evident.

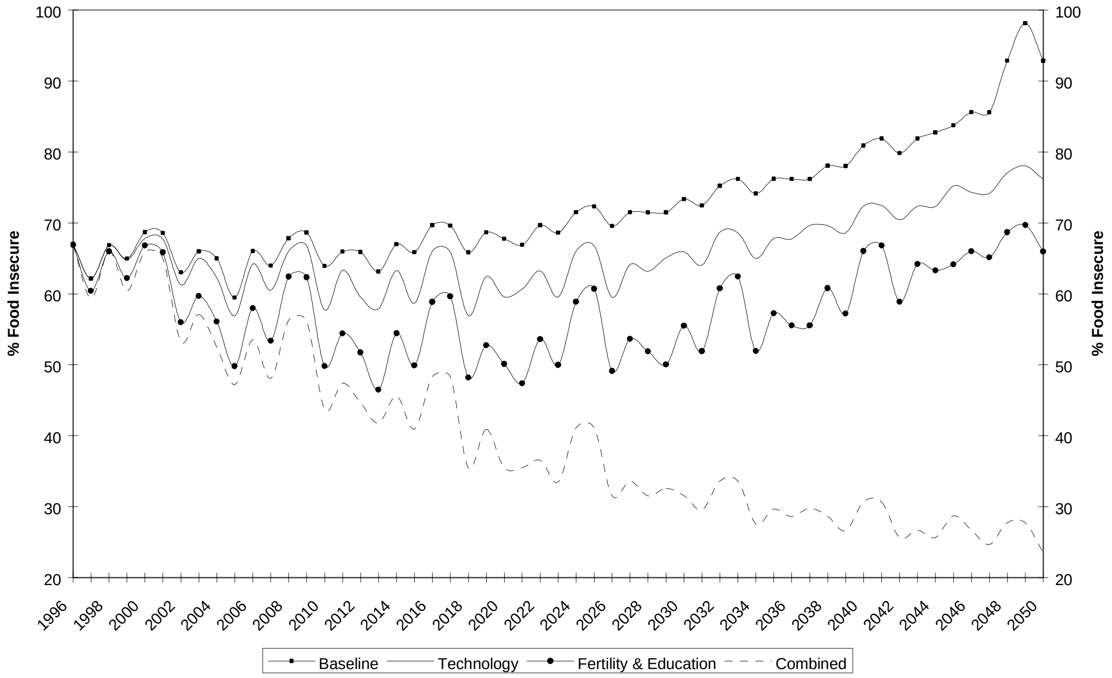
4.7 What needs to be done to revert the vicious circle ?

None of the scenarios presented so far are capable of reversing the vicious circle of high population growth, increasing environmental degradation and decreasing per capita agricultural outputs. Therefore, we have defined three other scenarios with the objective of getting an idea of the magnitude of the efforts that are required to break the negative development cycle in the case of Ethiopia.

All scenarios depart from the assumptions of the baseline scenario. The first entails increased technological inputs in agriculture. It assumes an annual increase in fertilizer use of 6 percent, in machinery use of 1 percent, in irrigation and technical education of 2 percent. This means that by 2030, fertilizer use will be more than 7.5 times higher than in the initial year, that irrigation and technical education will double and that machinery use will be 1.5 times higher. The second scenario assumes almost universal education (95 percent) in both urban and rural areas and a steeper fertility decline to reach a TFR or 2.4 by the year 2030. The third scenario combines the efforts in terms of the inputs in agriculture, education and fertility reduction.

The projection results, presented in Figure 5 in terms of the share of the population that is food insecure are clear. Only concerted efforts in the different sectors are likely to revert the negative vicious development cycle. Increased efforts in agricultural intensification or education and fertility alone, may be capable of improving the situation in the short run, but the proportions food insecure tend to increase again after 20 to 30 years.

Figure 5: the evolution of the percentage food insecure under the baseline, technology, fertility-education, and combined scenarios



Although the presented scenario assumptions of the combined scenario may not be practically feasible or realistic (they, for example, do not include the potential negative consequences of HIV/AIDS), the PEDA projections clearly illustrate that a solution for the food security problem in Ethiopia is not likely to be found in one sector alone. The exact constellation of policies to solve the food security problem may be different to include also migration, intensified industrialization and higher food imports, but the important message underlying the projection results is that a single sector solution is unlikely to be sustainable in the long-term, although the effect in the short run may be clearly positive.

Another lesson to be learned from the PEDA projections is that time plays a crucial role: the faster policies are implemented, the lower the efforts needed to revert the vicious circle. To give only one example: in the 'technology' scenario above, fertilizer use is assumed to increase at 6 percent a year to reach a level of fertilizer use that is more than 7.5 times higher by 2030 than in 1995. The same per capita agricultural outputs would be reached by 2030 if the fertilizer use would increase to only 5 times the level of 1995 but under the condition that this increase would be implemented within the first 5 years of the projection period (after which the fertilizer use remains constant).

5 Conclusion

Ethiopia's recent past has been a succession of political turmoil and famine, its future, if different, will highly depend on the proper management of the population-environment-agriculture nexus. With the majority of the population already living on the edge of survival, the challenges are enormous. Reversing the vicious circle of fast population growth, environmental degradation and a decreasing per capita agricultural production will require fast and concerted efforts in many sectors of society and the economy, and not alone in those that directly affect agriculture.

The Ethiopian Government is aware of the issues at stake and has developed policies and new institutions to tackle the development problems it is facing. After almost ten years of their formulation the time has come for an evaluation and possibly adjustment of the policies where necessary. Tools like PEDA could be useful to support the formulation of alternative policies, and also to assess and anticipate the effects of the proposed policy mix. To effectively use the PEDA model in such a manner, there remain a number of challenges to both scientists and policy makers. To open policies for evaluation, they should be accompanied by quantitative objectives and that requires a lot of political courage. On the other hand, it is the responsibility of scientist to further elaborate and specify the intricate interactions between demographic, socio-economic, environmental and agricultural variables to feed into models like PEDA and to make them better reflect country specific situations.

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