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Problems of energy security and potentials of environmental management in the assessment of the oil production peak and climate change

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1. Background and objectives of research

1.1 Significance of the topic

Humanity at its present level of development faces dual boundaries to its activity: on the one hand the anthropogenic greenhouse gas emissions as a limitation to output, and the decreasing and depleting resources becoming harder and harder to recover as a limitation on our input. The two limiting factors, the two most severe economical and societal problems of our age are closely linked together.

Human energy use is the primary and main source of anthropogenic climate change related emissions. Considering climate change as a key issue to the survival of our civilization it is vital to assess and regulate our energy use.

Our economic development seemed to be unscathed in the last century; the perspective of growth is omnipresent in the perception of our activities. Having undertaken a review of the publications and data, and considering the experimental and theoretical proofs available it seems obvious that our economic development and the extensive growth of energy consumption is closely correlated. Our goal nevertheless is development which is sustainable.

The concept of sustainable development was first outlined by the Brundtland-committee whilst preparing a special assembly of the United Nations as follows. Sustainable development satisfies the needs of the present generations without putting a limitation on the prospects of the future generations. In its implementation the energy supply of our societies plays a key role because our energy use requires the largest among of natural resources, and because of the imposed environmental impacts.

Energy supply is a key to our development. Security of supply is the key to the operation of developed nations and to the leveling up of developing nations. To maintain economical development it is imperative to secure continuous extension of energy supply at a relatively cheap price.

Energy use causes numerous environmental and healthcare problems in addition to other damages, exposing the ambivalence of our development in an obvious manner. Our energy use came to a – non-permanent – halt in the far or recent past only in case of severe crisis, wars, and economic recession. Global energy use bypassed 400EJ by the millennia, and only staggered to a halt by the recent economic crisis. Nevertheless, this effect is not envisaged to be long-lasting, energy demand is already rising as global recession is subsiding.

The problem is closely interconnected with climate change related concerns, since if we turn out to be incapable of dealing with energy problems, we would have to rely on non-conventional fossil sources and coal to satisfy our needs, which would not allow for the reduction of our greenhouse gas emissions.

To date there isn't any feasible and economically acceptable method to restrain our greenhouse gas – primarily CO_2 – emissions. Since the beginning of the industrial revolution the CO_2 concentration of our atmosphere increased with 30% mostly due to the combustion of fossil energy carriers. Developed countries express significant efforts to halt further increase (Hungary committed to reduce its emissions by 6%), but despite these efforts the atmospheric CO_2 concentration is forecasted to grow significantly in the next 50 years, a doubling is expected due to the developing nations growing emissions. This currently is the single largest problem of fossil energy, if the assumed implications (melting of ice caps, seal level rise, etc.) of climate change are verified then as a protective measure for the present already in the next decades we can expect a serious limitation on our carbon emissions, where the Kyoto Protocol or other economic measures will seem awkward in comparison.

It is imperative therefore to consider climate change policy goals when assessing energy scenarios

Our global crude oil consumption plays a key role in the tendencies and problems outlined above. Oil bears the most significant role in our economy as an energy carrier, as described in depth by many sources, an occasional change or crisis in oil supply can harm our economy on many sensitive areas in an unexpected way.

1.2. Objectives and goals laid down in the dissertation

In the dissertation I strive to analyse the challenges and possible choices facing our societies built on the present consumption patterns and growth orientation: societal and economic challenges, energy supply problems and the fallacy of the present paradigm of economic growth.

A general objective of the dissertation is to prove in an exquisite manner the key importance of energy use in our economies: energy input is considered as a key factor capable of limiting our growth and endangering our biosphere. Constraining or obliterating our energy use will threaten the very level of our economic development and society.

The aim of the dissertation is to present the global and domestic context of energy use and economic development.

The goal is to identify and verify the connection between the domestic energy use and economic growth, to characterise its strength and direction, and to assess its possible integrated quality.

Another goal is to present some new assertions on the economic impacts of energy use and energy efficiency improvements by extending the Solow-model with energy sources as input to production.

A further goal is to present domestic scenarios of energy use, and to give some suggestions for the implementation of the national climate change policy targets.

Besides these, the aim is to examine the effectiveness of domestic energy efficiency and energy savings measures from the aspect of reduction of energy import dependence and greenhouse gas emission mitigation.

1.3. Hypotheses

In the dissertation the following hypotheses are assessed in concordance with the objectives and goals set out.

- Economic growth in its present form can only be secured if energy use increases.
- Both internationally and domestically a strong connection exists between economic growth and energy use.
- Present, planned and possible domestic energy savings and GHG-mitigation measures are effective, although economic growth might require more significant efforts for the implementation of domestic climate change goals and international commitments. There is a synergic relation between efforts undertaken to solve energy problems climate change mitigation.
- The extension of the Solow-model's classical inputs – capital and labor – with energy is reasonable and brings about new results in equilibrium solutions and assessment of energy efficiency.
- Preparation to the forthcoming energy crisis and climate change mitigation and adaptation is a strategy well worth selecting in the course of our future actions, its global optimality can be validated by game theoretical means.

2. Methods and theme[1]

According to the statements made beforehand, energy use and environmental problems are inseparable. It is therefore advised to assess the strength and direction of the connection between these two factors.

According to the objectives and goals set out earlier, it is necessary to examine the potential of extending the mainstream approach of economics with energy use in order to gain more precise results on the verifiable impacts and benefits of renewable energy and energy efficiency measures.

On the other hand when assessing domestic energy consumption it is reasonable to evaluate the connection between energy consumption and macroeconomic output. A further task is the reliable modeling of expected future domestic energy trends, and the proper methodological assessment of mitigation measures. The impact of domestic greenhouse gas mitigation measures should also be assessed.

Considering all these tasks, the methodological approach is presented according to the following. First, through some methodological questions I describe the non-linear equilibrium model applied for energy modeling. I continue with the framework used for modeling greenhouse-gas emissions, and I close the chapter with the applied statistical methods and macroeconomical models.

2.1. Forecasting energy consumption with the ENPEP/ BALANCE model

In modeling the energy sector the fundamental task was the reliable forecast of the domestic energy consumption. This was accomplished by the application of the ENPEP modeling framework's BALANCE model to the domestic sectoral energy forecast. The BALANCE model is a general non-linear equilibrium model developed by the Argonne National Labs and the Department of Energy of the U.S.A. The modeling framework was used in numerous earlier occasions, its domestic application was supported by its broad international use, in Europe it was adopted and applied more than 40 times, and worldwide applications are even more widespread.

The central requirement of a comprehensive energy analysis is the evaluation of alternative configurations of the energy system that will balance energy supply and demand. The BALANCE Module of ENPEP is designed to provide the planner with this capability. BALANCE uses a non-linear, equilibrium approach to determine the energy supply demand balance.

The objective of the ENPEP modeling framework is the evaluation of alternative configurations of the energy system that will balance energy supply and demand on the energy market, the simulation time step is one year for up to 75 years.

[1] Numbering of the dissertation is maintained in the thesis booklet

For its simulation, the model uses an energy network which represents all energy production, conversion, transport, distribution, and utilization activities in a country or region, as well as the flows of energy and fuels among those activities.

The environmental aspect is also taken into account by calculating the emissions of various pollutants. In addition to energy costs, the model also calculates the environmental costs. These costs can be used to affect the solution found by the market equilibrium algorithm.

The main task of the software model is to provide an analytical tool and capability of system analysis for energy and environment analysis and for long term energy planning. The core issue of this is the evaluation of alternative scenarios leading to equilibrium, which can be undertaken by BALANCE. BALANCE uses a non-linear, equilibrium approach to determine the energy supply demand balance. For its simulation, the Model uses an energy network that is designed to trace the flow of energy from primary resource (e.g., crude oil, coal) through to final energy demand (i.e., diesel, fuel oil) and/or useful energy demand (i.e., residential hot water, industrial process steam). Demand is sensitive to the prices of alternatives. Supply price is sensitive to the quantity demanded. In its operation, BALANCE simultaneously tries to find the intersection for all energy supply forms and all energy uses that are included in the energy network. The equilibrium is reached when the model finds a set of prices and quantities that satisfy all relevant equations and inequalities. The simulation time step is one year for up to 75 years. However, the Model is typically used to analyze a 20 to 30 year forecast period.

The model processes a representative network of all energy production, conversion, transport, distribution, and utilization activities in a country (or region) as well as the flows of energy and fuels among those activities. The energy network in the model is constructed with a set of submodels or building blocks, called *nodes.*

The user connects the nodes with a set of links. The links represent energy and fuel flows and associated costs among the specific energy activities. Links convey this information (i.e., price and quantity) from one node to another. The energy network is developed by defining the energy flows among the different types of nodes for a given base year. All sectors of the energy supply and demand system are included in a typical BALANCE analysis.

The comprehensive modeling of energy sector allows for the assessment of prices, extractions, consumption in a uniform framework, in a contextual approach. This approach ensures that the supply and demand is in equilibrium at any level of the energy transformation structure, and that future energy use correlates with energy prices, that is, cheaper energy carrier is preferred over more expensive ones.

2.2. Methodology for greenhouse gas emissions forecast

For the estimation of domestic greenhouse gas emissions the HUNEMITS model and database was used, which contains sectoral data necessary for an objective and realistic impact assessment of domestic policies and measures. The first in country use of the recently developed model was its application during the preparation of the 5th National Communication of Hungary to the UNFCCC. A brief overview of the model is presented herewith.

The model contains technical-economical characteristics for more than 700 emission abatement (mitigation) measures; data includes among others mitigation costs, investment costs, rate and time of return, maximal implementation rates, and present implementation.

The model requires activity rates to estimate consumer side demand, and derives the sectoral and total emission of the economy using the respective emission factors. Activity rates are user inputs coming from BALANCE runs.

The core of the model is the calculation module, which is supplied by data by three other (blue colored) modules:

- The 2005-2025 reference scenario (see Chapter 2),
- A list of GHG mitigation measures for each sector + characteristics (see Chapter 4),
- General input data per sector such as energy prices, interest rates, CO_2-emission factors and physical growth factors.

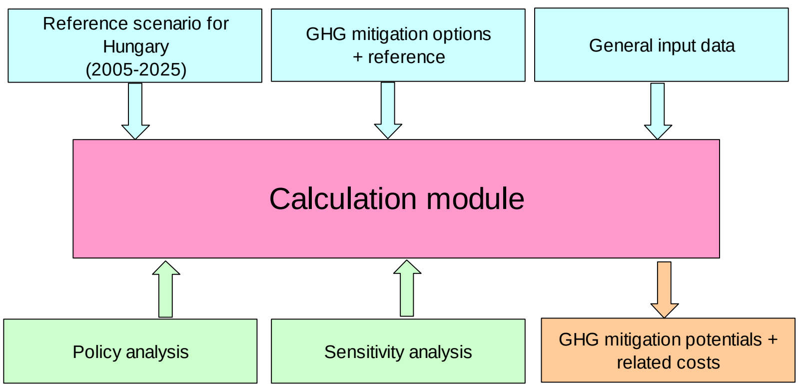


Chart 3.2. Overview of the HUNMIT model

The green coloured boxes are linked to a user interface and allow the user of the model to define policy scenarios and/or to carry out sensitivity analyses. Examples of policy scenarios are:

- Cost effective GHG reduction potential at different carbon cost levels at country or (sub)-sector level.
- Total costs (society/end-user) when setting a GHG reduction target at country or (sub)-sector level.

- Total costs (society/end-user) for meeting a specific CO_2 target, or meeting a specific RES target

2.3. Analytical framework for the assessment of GDP and energy

The analysis of time series carries many challenges, among other the problem of stationary series. Engle and Granger (1987) suggested a new methodology for time series analysis in their article by giving analysis of stationary series a new approach. They showed that in case of independent time series if the degree of integration *(d)* matches for the two series and the residuals from the linear regression of the two time series follow an I*(b)* process, then the original time series follows a *d,b* order cointegrated process, which was denominated by *CI(d,b)*, and this way the difficulties coupled with forecasting of transformed time series is evaded.

Cointegration analysis comprises the following tasks. Let u_t and v_t be two given time series. First the degree of integration has to be defined. Non-stationary time series can be problematic, especially if they follow a unit root process (an *I(1)* process), in this case heteroscedasticity causes problems, and the model can not be used for forecasting. Tests can be undertaken for different values of the factor of integration, intercept, and lag to identify the order of integration.

Then if the two given processes are identically integrated, the cointegration analysis can be undertaken, a sufficient condition for this is the stationarity of the residuals from the OLS estimation of (1). The most straightforward method is the Johansen maximum likelihood cointegration test, but the before mentioned analysis of the integration of the residuals is also acceptable.

$$v_t = \phi u_t + \varepsilon_t \qquad (1)$$

In case the residuals of (1) can be characterised as a white noise process, then there is one cointegrating factor which characterises the long term relationship of the two series; if there are more cointegrating factors, then there can be multiple cointegrating vectors. Afterwards a so called vector error correction model is necessary to test the exogenity of the variables further, an example for a VECM is this form:

$$\Delta v_t = \alpha + \sum_{i=1}^{k} \Delta u_{t-i+1} + \sum_{j=1}^{m} \Delta v_{t-j} + \delta ECT_{t-1} + \varepsilon_t \qquad (2)$$

where *α, β, γ, δ* coefficients can be estimated by vector-autoregression, Δ is the difference operator, *φ* the cointegrating factor, ECT is the error correction term given by (1). The causality of the variables can be assessed by the method suggested by Masih and Masih (1997), the hypothesis is that the stronger causality gives a higher explanatory value.

2.4. Macroeconomical modeling of energy sources

Some notes on the Solow-model were given in chapter 3.4. of the dissertation. Through the extension of the model the aim is to assess the effect of energy as a macroeconomic input on the equilibrium, and to examine the impact of energy efficiency.

Denote the macroeconomic output with the usual variables:

$$Y = K^{\alpha}(\eta_E E)^{\beta}(\eta_L L)^{\gamma}$$
$$\alpha + \beta + \gamma = 1 \Rightarrow \gamma = 1 - (\alpha + \beta) \qquad (1a)$$

where
K – amount of capital used
E – amount of non-renewable natural resources and/or energy carriers used
L – amount of labor used
$\alpha+\beta+\gamma=1 \Rightarrow \gamma=1-(\alpha+\beta)$: $\alpha,\beta,\gamma>0$ Constant scale of return is assumed (the economy works at its efficient interval) $\alpha+\beta+\gamma=1 \Rightarrow \gamma=1-(\alpha+\beta)$: $\alpha,\beta,\gamma>0$ denote the input factors proportion used for a unit of output in the economy[2].

It is assumed that the production function is a Cobb-Douglas function (or it can be transformed with a monotonous transformation from a homothetic function). In the production function energy practically denotes the total energy demand of the economy, or in a broader perspective can be interpreted as demand for natural resources. My further assumptions concern the dynamics of the respective input factors:

$$\dot{E} = \varepsilon E$$
$$\dot{K} = sF(K,E,L) - \delta K = sY - \delta K \qquad (1b)$$
$$\dot{L} = nL$$
$$s, \varepsilon, n, \delta > 0$$

Energy use, labor supply (or population change as it is assumed to follow the same trend) show an exponential tendency, where ε and n indicate energy use and population growth rates respectively, s denotes rate of savings and δ amortisation rate.

The first equation shows the dynamics of energy use, the second shows the conventional assumption on capital dynamics (characterised with the difference between savings and amortisation). The assumption on labor supply or population change depicted in the third equation of (1b) is the result of mainstream economics and numerous publications.
The following further assumptions are made on energy efficiency which express the dynamics of improvement

$$\dot{\eta}_L = h_L \eta_L$$
$$\dot{\eta}_E = h_E \eta_E \qquad (8)$$

The η-s are not thermodynamical efficiencies[3], but are simple multiplicators and can better express the impact of efficiency change for economical analysis.

[2] In any case normalisation of the exponent can be applied.
[3] A possible transformation between thermal efficiencies (η_{TD}), and productive efficiencies(e.g. η_L) can be as follows: $\eta_L = 1/(1-\eta_{TD})$.

3. Results

When outlining the concept of sustainable development and the future development trends it is important to understand the long term interrelation between economic development and energy consumption. Investment into cleaner technologies can also be interpreted as an energetical transition, its significance goes beyond the revolution of existing and amortising capital stock and defines the boundaries of our future economic development (if we consider our energy supply a limit to growth – we have every reason for this).

The task is significant, since a well-founded energy-economic model can aid the evaluation of growth potential allowed by the respective scenarios, and vice versa, how challenges of energy supply can be met without endangering economic development.

Primarily the connection of energy use and economic development has to be verified, for this a cointegration model of domestic energy use and GDP is tested, and based on the verified model a neoclassical growth model is extended with energy use. Through analysis aided by mathematical-economical toolwork it is demonstrated how introduction of energy and energy efficiency in the Solow-model modifies equilibrium solutions and results in a more sustainable alternative development scenario.

Certainly it is a question if the series of steps requiring significant effort and socio-economic adaption are reasonable.

For this question a simple application of the available methodology of game theory gives answers, in the second step it is verified that global action is a reasonable and optimal strategy, and Hungary as an EU-member is obliged to make its proprietary steps.

Hungary's international commitments to climate change mitigation and adaptation and the legislation derived from the relevant EU guidelines provide a quantifiable framework. If we want to achieve a structural change in our economy by implementing our energy policy and the EU's directives on energy policy, it is indeed important to analyse the domestic energy sector, and to assess the impact of existing and possible measures. This is even more necessary since the available resources are limited, and the answers of successful business management and good governance need to be formulated to deal with the depletion of energy sources.

The impact assessment of the domestic measures has to provide clear answers on the achievable results and climate change mitigation potential in the framework of sustainable development .

Based on the energy scenarios the HUNMIT model was used to develop three emission scenarios encompassing a scenario fulfilling the Cancun agreement cap that is a 30% reduction of emission.

3.1. A cointegration model of domestic energy consumption and economic development.

To analyse the connection between domestic energy consumption and GDP the approach described in the methodological section was applied (GDP and energy consumption stationarity analysis, unit root process analysis, assessment of degree of integration, identification of cointegration equation, establishment of a vector error correcting model, testing)[4]. GDP data were provided by KSH Ecostat, energy data come from Eurostat. The GDP time series is a fixed price time series, however it was indicated that KSH recalculated data beginning with 1995, data before this time was developed with a different methodology. Despite these considerations the analysis was performed for a time period beginning from 1950, as a time series from 1995 would contain critically low amount of elements after already two differentiations, and results were not significant in this case. The time series were logarhitmised due to the different scale and for easier description. Chart 4.1. provides a good illustration of the similar behavior of energy consumption and GDP.

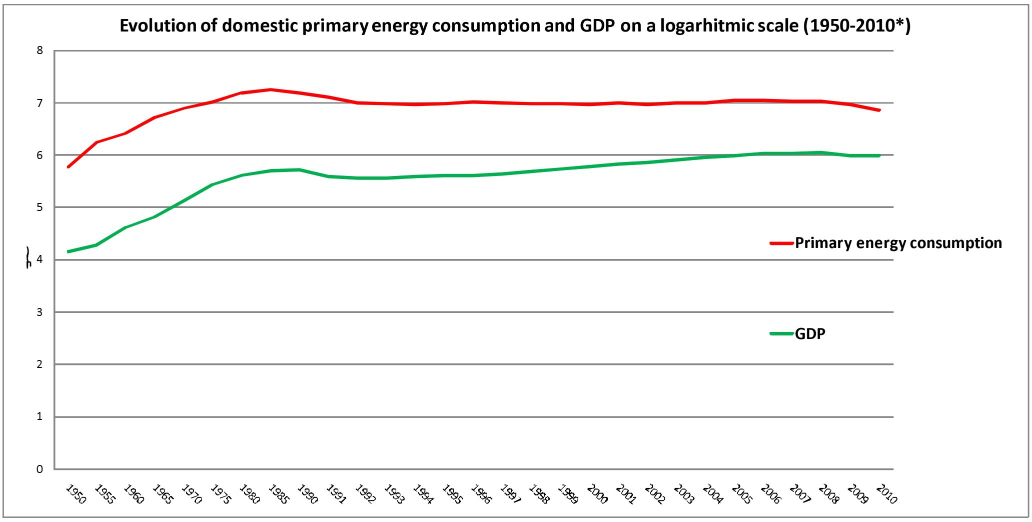


Chart 4.1. Domestic primary energy consumption and GDP on a logarhitmic scale , (1950-2010[5])

source: Ecostat, own ed.

In the first step I identified the integration factor of the two time series with unit root tests (Augmented Dickey-Fuller test or ADF). Results showed that both time series are I(2) types with 95% confidence. Performing the Johansen cointegration test the result gained was the following cointegrating equation describing long term equilibrium with higher than 95% confidence:

$$\ln E_{t-1} = \underset{0.50851}{0.603442} \cdot \ln GDP_{t-1} + 3.89389 + u_t$$

[4] For the analysis, Eviews 5.1. was used.

[5] 2010: estimated data extrapolated from the first three quarters

The equation underlines the conjecture that our energy consumption significantly depend on our GDP-level.

The vector error correcting model (VECM) explains the deviation from the long term equilibrium with applying lagged variables, a vector autoregression model would give a mis-specification due to the presence of cointegration in the model.

The optimal lag for the VECM was automatically selected according to the Schwartz-information criterion, the model is as follows:

$$\Delta \ln E_t = -\underset{0.14722}{0.0892950} \cdot (\ln E_{t-1} - \underset{0.04641}{0.603442} \cdot \ln GDP_{t-1} - 3.89389) - \underset{0.12267}{0.384743} \cdot \Delta \ln E_{t-1} -$$
$$- \underset{0.07606}{0.08482} \cdot \Delta \ln E_{t-2} + \underset{0.12875}{0.332045} \cdot \Delta \ln GDP_{t-1} + \underset{0.10722}{0.09607} \cdot \Delta \ln GDP_{t-2} - \underset{0.00649}{0.011946} + \varepsilon_t$$

The model has a sufficient explanatory value, and the residuals are stationary, $R^2_{adj} = 0.937621, \varepsilon_t \sim I(0)$. If we select the other direction of explanation the explanatory force of the model would be reduced but still significantly high (R^2_{adj} =0.7548). The interconnection is statistically significant, this indicates that there is a co-integrating relationship between energy consumption and GDP.

Using the estimation results of the error correction model, the following is the result for the long run relation

$$\ln E_t = 0.3030942 \ln GDP_{t-1} - 0.235975 \ln GDP_{t-2} - 0.09607 \ln GDP_{t-3} +$$
$$+0.525962 \ln E_{t-1} + 0,299923 \ln E_{t-2} + 0.08482 \ln E_{t-3} + 0.35965 + \varepsilon_t$$

From the above equation it follows that the energy consumption in a specific year is strongly influenced by the GDP in the previous two years, and the energy consumption in the previous two years. The influence longer lagged variables is negligible.

Testing for Granger-causality shows that in the case of an I(1,1) lag the GDP Granger-causes energy consumption, in case of I(2,2) there is a very high probability for bidirectional causality.

3.2. Macroeconomic modeling of energy as an input factor

The deductions in the dissertation led to the following conclusions. In the extended model the production per capita (PPC) is influenced by energy consumption, the latter's increase increases PPC. Output grows proportionally with the difference of energy use and labor use, increase of labor use might not increase output automatically since self consumption requires higher resource allocation, and our growing or stagnant population economy can increase only if energy use or resource use is increased (efficiencies at this point are not yet considered).

Balanced state growth

If we examine the usual balanced state growth trajectory, then the output-capital ratio has to be constant, then the change in per capita production is :

$$\frac{\partial \ln(y)}{\partial t} = h - \frac{\beta}{1-\alpha} n = \frac{\gamma h_L}{1-\alpha} + \frac{\beta h_e}{1-\alpha} - \frac{\beta}{1-\alpha} n = \frac{\gamma h_L + \beta(h_e - n)}{\beta + \gamma} \qquad (17)$$

Results show that the negative impact of population or labor-supply increase shows proportionally to the energy/resource use (β), and increase of efficiency causes PPC increase. It can be concluded that if energy consumption is fixed in every period then labor supply's effect on output is due to the reduction effect on output of increasing energy consumption of the population. According to the model efficiency increase proportionally increases output of the economy

Impact of energy efficiency improvement

It was assumed that our energy use can be fixed at a level, for example successful governmental and civic efforts made this possible. Further simplifying assumptions are that our labor use reached its optimal efficiency, which can not increase further, η_L=1.

Let's assume that societies labor supply (population) grows faster if production per capita bypasses a critical level (Y_e/L_e). An equilibrium is sought for where capital-output proportion is constant and according to the initial assumption, the efficiency improvement rate and population growth rate is equal, $n=h_e$, thus ensuring that population increase does not cause energy consumption increase (E_t= const., for simplicity E_t =1 for all t), then the following result stands:

$$\kappa_e = \frac{s}{h_e + \delta} \qquad (21)$$

Equilibrium capital growth rate is – if we assume that energy efficiency improvement is secured (by investments, utilisation of renewables, energy savings measures) thus stabilising energy consumption – equal with the quotient of savings rate and amortization rate plus energy efficiency improvement rate.

If we substitute into the output per unit of labor along the equilibrium growth (κ_e) trajectory and utilise our assumption on efficiency we receive the following result after simplifications:

$$Y = K^{\alpha} \eta_E^{\beta+\gamma} \Theta \qquad (25)$$

where the denotation

$$\eta_L^{\gamma} \lambda^{\gamma} = \Theta$$

was used since and we relied on the assumptions that energy use was constant and η_L was constant, therefore we could represent its product with λ (which also is constant) with another constant denoted with Θ which characterises a country with several other macroeconomic and social constants.

Assessing the result in (25) it is visible that in a country where energy consumption was stabilised, labor efficiency is optimal the output of an economy or its macroeconomic product can be increased by a higher ($\beta+\gamma$) than expected (β) proportion with increasing energy efficiency.

This result gives a proof to the conjecture that energy efficiency improvement can intensively, without further energy consumption provide economic development. It has to be noted that energy efficiency was interpreted in the model as a multiplicator expressing the energy gained from the unit of energy invested (a similar concept is EROI as described in the dissertation subchapter 2.10). It is clear from this definition that measures improving energy efficiency thus without any strong conceptual error incorporate renewable energy measures, since with one unit of energy invested (e.g. installation and operation of renewable capacities, etc) we gain a very high margin of energy returned, increasing the macro level energy efficiency.

Conclusions
The above analysis shows that consideration of energy as a macroeconomic input factor significantly modifies equilibrium trajectories and solutions of the conventional model.

Increase of energy consumption in any case – although extensively – increases macroeconomic production. Combined with population increase nevertheless this extensive growth quickly meets its limitations of depleting resources and environmental problems.

With the introduction of energy efficiency and its dynamics numerous important results are gained in my opinion. One is that the equilibrium capital intensity can be reduced by increasing energy efficiency, another is that increase of production per capita is proportional (weighted) with energy efficiency improvements.

In the economies which stabilise their energy consumption improvement of energy efficiency leads to increases in macroeconomic output higher than proportional to energy's role in production.

This leads to the conclusion that energy efficiency measures beside their direct energy policy and environmental benefits have direct macroeconomic benefits excluding the trivial economic reasons (cost reduction, rationalisation).

3.3. Possible estimation and application of a domestic production function

The domestic production function in the form of *(K,L,E)* was estimated for a simple application of (25).
The data used for the estimation came from Eurostat and KSH. The validity of the estimation is limited, since the estimation was performed on the data for 1994-2009, first because data availability was limited, and the methodology of GDP calculation was changed in beginning from 1994. Not lastly, it is very likely that there was a structural break between the periods before and after 1993 (or 1990). The low number of elements nevertheless reduces the value of the estimation.

After running Eviews the following result is gained with good fitting (R^2_{adj}=0.984) for the logarhitmised time series

$$\ln Y = 0.497 \cdot \ln E + 0.389 \cdot \ln K + 0.145 \cdot \ln L$$
$$\Rightarrow$$
$$Y = E^{0.48} K^{0.38} L^{0.14}$$

for macroeconomic production, energy used, capital goods, and labor utilised.
The next step is the assessment of the domestic Energy Efficiency Action Plan's effect on macroeconomic production. According to the Action Plan, 12% energy efficiency improvement would be achieved if the planned measures are implemented.

For simplicity everything else is assumed to remain unchanged, and the conditions under (25) to be fulfilled – among others energy use is stabilised[6] – then the macroeconomic output can be deduced with the aid of comparative statics:

$$Y_0 = K^{\alpha} {\eta_{E0}}^{\beta+\gamma} \Theta$$
$$\eta_{E1} = 1.12 \eta_{E0} \Rightarrow$$
$$Y_1 = K^{\alpha} {\eta_{E1}}^{\beta+\gamma} \Theta = K^{\alpha} (1.12 \eta_{E0})^{\beta+\gamma} \Theta = 1.12^{\beta+\gamma} K^{\alpha} {\eta_{E0}}^{\beta+\gamma} \Theta =$$
$$= 1.12^{0.48+0.14} Y_0 = 1.07279113 Y_0$$

That is, domestic product would be increased with 7% if the assumed 12% efficiency improvement is undertaken according to the data available. If no conditions are made then efficiency improvement would roughly enhance production by 5.6% compared to the base value everything else the same.

3.4. Peak oil and a game theory approach

Considering generally the future issues of energy management and peak oil, the question is inevitable, what are the possible strategies that can be followed, what steps have to be made, and what the likely outcomes are. The methodology available in the scientific field [Rasmusen, 1989, Molnár S. et al, 2010a] provides an easy approach to use game theory to answer if preparation is reasonable and optimal.

There are two players in the game. One is mother nature, whose strategies are the possible depletion scenarios (exogenous for use), the other is the totality of human governments, the Government, which selects a strategy. Game has one round and does not repeat, payouts are unequivocally given.

Concerning nature we can have only assumptions, as it is not known exactly how big our oil reserves are, when the oil production peak arrives, and what is the proportion alternative energy sources can replace. We don't know nature's probabilities on her strategies, and the government has to find an optimal choice lacking this information. Primarily the avoidance of critical conditions is the goal, targeting the least painful (with

[6] Note that stability of energy consumption only applies to non-renewables.

least social cost implementable) scenario for transition. The game is not a full information one, and probably can not even be made like that even with great research efforts.

Risks in the game are relatively high, both due to the negative outcomes high negative payout values, and the relatively low number of acceptable outcomes. Radical action also has its risk, as it can result in staggering economic development, shaky incomes, in general the reduction of wealth can result from the reallocation of resources. Nonetheless the lack of action can increase the severity of the negative outcomes. The time available for transition is an important factor as the number of sufficient outcomes can significantly reduce if we don't start action well before the oil peak. Robert Hirsch in his senate report states that the problem is unlike any we met before, previous energy transitions (wood to coal, coal to oil) were stepwise and forward looking, peak oil and the posterior period will be rude, and bring a radical change.

For the identification of the payouts of the strategy pairs a payout matrix was outlined. The outcomes denoted with a Roman number were named and shortly described, the remaining outcomes were not characteristic end-states, but transition between some apices, and inherit the two neighboring outcomes attributes in a mixed manner, therefore a simple interpolation was deemed sufficient for their calculation. The second column of the cell contains the expected value of the payouts.

In Table 4.3. the respective outcomes, payouts are given in a scale ranging from -50 to +50 (-50= absolutely not desired, 50= most desired).

Table 4.3.Payout matrix by decision variables of the players

Payout matrix	**Choice of nature**									
Choice of government	***F1 Superoptimistic***		***F2 Optimistic***		***F3 Plateau***		***F4 Pessimistic***		***F5 Collapse***	
Years until peak	*40+*		*15-30*		*10-15*		*5-10*		*0-5*	
P(~)	10%		15%		35%		25%		10%	
1. Privatisation of natural resources, globalisation, maintenance of western lifestyle	X. -10	**-1**	II. -30	**-4.5**	IV. -35	**-12.25**	VII. -40	**-10**	I. -50	**-5**
2. Comprehensive preparation	IX. +50	**+5**	+30	**+4.5**	VI. +20	**+7**	-10	**-2.5**	III. -20	**-2**
3. Regionalisation with sustainable communities	VIII. +30	**+3**	+15	**+2.25**	V. +10	**+3.5**	-15	**-3.75**	VII. -20	**-2**

Source own ed.

Before choosing the optimal strategy it is worth to consider the alternative costs. In table 4.5. the alternative costs by strategies are shown, that is if a given state of nature is realised, then compared to the optimal strategy how much the given strategy "costs", how much worse it is.

Table 4.5. Alternative costs by strategies

Alternative costs	Choice of nature				
Choice of government	***F1 Superoptimistic***	***F2 Optimistic***	***F3 Plateau***	***F4 Pessimistic***	***F5 Collapse***
1. Privatisation of natural resources, globalisation, maintenance of western lifestyle	-6	-9	-19.25	-12.5	-7
2. Comprehensive preparation	0	0	0	0	0
3. Regionalisation with sustainable communities	-2	-2.25	-3.5	-1.25	0

Source own ed.

The table shows comparison to the maximum that could be achieved should nature play a given strategy. It is well visible that the broad preparation, strategy number 2 is the dominant strategy of the government.

Maintenance of the western lifestyle is not viable as it does not consider the change in geopolitical realities. Although the strategy of sustainable communities and regionalisation results in lower living standards, but gives a near-optimal solution.

Contrary to the solution above the reality today is that the national governments play a non-cooperative game in the form of economical-political competition for resources. Here it can easily be shown that the dominant strategy is an exclusive access to resources by a military-economical force thus closing out other countries access thus rendering them subjugates. This nevertheless conserves a status quo which can not be sustainable on the long term. It remains to be seen if we can think in a perspective which can solve this controversy.

3.5. Domestic forecast on energy consumption

The EU's Energy Directorate declared the 20/20/20 directive[7] in January, 2008 which aims to reduce greenhouse gas emissions from energy use with 20%, increase renewable energy use with 20%, while improving overall energy efficiency with 20%. This ambitious program is based on the data of 2005 and has to be implemented until the time horizon of 2020. In concordance with the Directive the EU set out energy efficiency action plans (Energy Efficiency Action Plan, EEAP, Energy Saving Action Plan, ESAP) for the member states which focus on three areas, domestic use, industry, and transport. Action plans set out short term tasks for the period until 2014.

The national strategies and action plans (National Energy Efficiency Action Plans – NEEAP), were formulated in adoption to the EU action plans. The Hungarian Action Plan was accepted in 2008, and submitted to the EU. This action plan outlines those activities which if applied enable Hungary to reduce its energy use from 2008 to 2016 annually by

[7] Climate Change and Energy Package ("20-20-20 package"), Renewable Energy Directive (2009/28/EC), the EU ETS Directive (2009/29/EC), the Fuel Quality Directive (2009/30/EC), the Carbon Capture and Storage Directive (2009/31/EC), Decision No 406/2009/EC on effort sharing and Regulation (EC) No 443/2009.

1%. The Action Plan is an important tool for Hungary to comply with the EU obligations of 20% reduction by 2020.

For achieving these goals the Hungarian NEEAP identifies the following areas:

- household sector building stock,
- institutional sector building stock,
- systems of energy distribution and transformation,
- transport, freighting,
- typical energy consuming goods capable of influencing expected future energy demand and usage patterns

During the modeling the measures under implementation and planned measures were assessed (app. M2.1.), which if used effectively can reduce Hungary's energy consumption with 1% annually for a 12 year period of 2008-2020. This means that for the modeling I assumed that efficiency can be further improved beyond the timeframe of the NEEAP.

For the domestic energy consumption forecast some further data was used (Fucskó et al. [2008]). During energy demand modeling I also examined the maximal achievable savings potential, which is characterised by the set of technically-economically implementable measures.

For the calculation of energy savings measures, the figures provided in the NEEAP published by the Ministry of Economic Affairs[8] and the Renewable Action Plan[9] were used and numerous other data and sources available.

Base year for the forecast was 2005 in order to match the NEEAP's base year, and to match the emission forecast model's base year. Modeling timespan was until 2025. Indicative assumptions are shown in Table 4.6.

Table 4.6. Assumptions used in modeling

Variable	2010	2015	2020
GDP-growth	+4,05%	+3,20%	+4,43%
Electricity production (TWh/a)	39 ,151	46, 136	52 ,544
Emission factor (electricity prod.)	729.9	691.7	668.9
Populace (M souls)	10,0	9.,80	9.60
Disposed communal solid waste (Mt)	2.8	2.8	2.2
Passenger vehicle transport, Mkm	21365,25	24778,72	28501,19
Thermal eff. of condensing power plants (η)	0.35	0.40	0.41

Source own ed.

[8] National Energy Efficiency Action Plan (2019/2008 (II.23.) Govt. decree.

[9] Hungary's Renewable Energy Policy, 2007-2020, GKM, 2007

For the modeling the Hungarian Transmission System Operator Company's (HTSOC) middle and long term capacity plan[10] was also taken into consideration.

Results for the energy demand forecast are contained in a sectoral breakdown in Table 4.8.

Table 4.8. Expected sectoral energy demand (PJ)

	Households	Industry	Transport	Tertiary, services, etc.	Power sector	Total
2005	289.19	253.77	253.26	204.13	301.15	1301.5
2010	301.15	271.32	292.51	215.48	299.36	1379.84
2015	297.18	308.83	328.97	220.9	300.21	1456.11
2020	290.39	349.94	353.9	225.97	311.31	1531.5
2025	281.83	404.5	368.54	227.68	328.76	1611.33

Source: own calculations

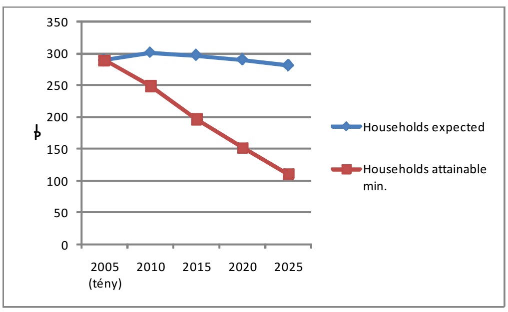
Assuming the highest possible savings the optimal scenario is described in Table 4.9.

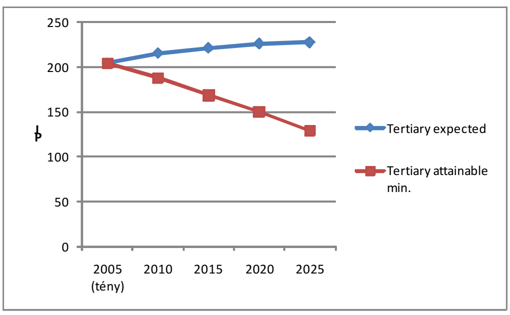
Table 4.9. Domestic minimal energy demand in the respective sectors (PJ)

	Households	Industry	Transport	Tertiary, services, etc.	Power sector	Total
2005	289.19	253.77	253.26	204.13	301.15	1301.5
2010	248.91	248.25	276.59	188.02	219.78	1181.53
2015	196.28	283.78	295.27	168.27	175.96	1119.54
2020	151.95	322.71	280.02	150.05	180.54	1085.26
2025	110.27	373	277.63	128.97	232.04	1121.92

Source: own calculations

Energy demand in the respective sectors is shown in Charts 4.3a-d.



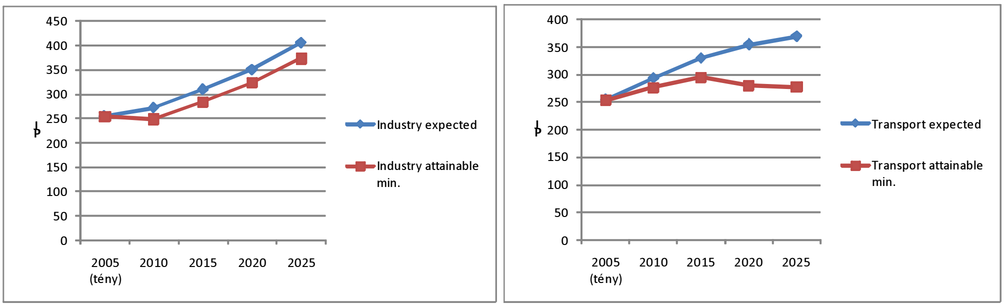


Charts 4.3a-b. Expected and potentially minimal energy consumption of households and tertiary sector

Source: own calculations

[10] Middle and long term capacity plan for the Hungarian power system, 2007, Hungarian Transmission System Operator Company Ltd.

It is well visible that the highest savings potential can be found in the households and tertiary sector. There is no policy capable of energy reduction in the transport sector. This matches the tendencies in Europe.



Charts 4.3c-d. Expected and potentially minimal energy consumption of industry and transportation

Source: own calculations

According to the data available, the industry also does not offer too high energy savings potential, although the real picture might be somewhat different, further research is required here.

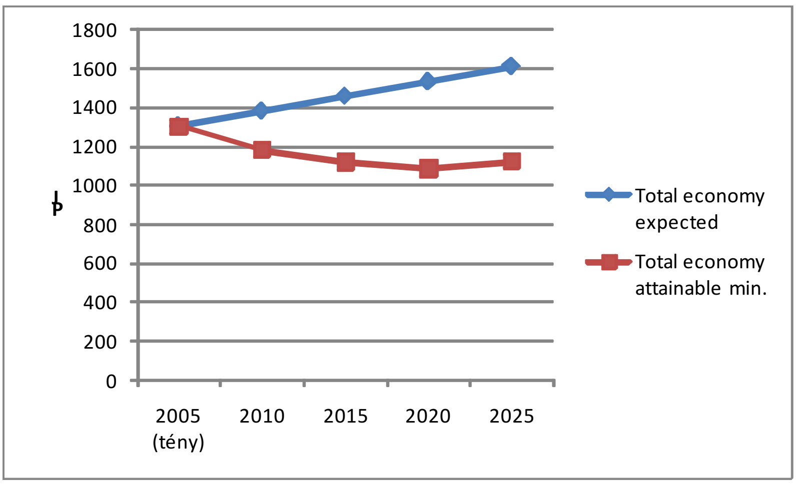


Chart 4.4. Total forecasted energy demand as expected and as potentially minimal

Source: own calculations

Results show that the potential energy efficiency and energy saving measures can produce an overall significant energy saving impact. The largest effect can be achieved in the households and tertiary sectors. Nevertheless even the most extensive application of measures can not decrease energy consumption to a larger degree

3.5. Domestic forecast on greenhouse gas emissions

Considering the tendencies described above, the emission forecast model runs were undertaken accordingly, as summarised hereby briefly.

Modeling considerations and assumptions

The HUNMIT model in itself does not contain the complete domestic greenhouse gas emission verticuum. The mapping of tertiary sector is incomplete, the model does not contain industrial N_2O emissions, emissions from agricultural energy use, and other small sources. The first step was to give a full coverage of domestic emissions, this was achieved by the ENPEP/IMPACTS modeling subsystem. The extension of HUNMIT allowed for a full coverage of domestic GHG emissions.

The fundamental strength of the model is that it enables the construction of sectoral marginal mitigation cost curves from the measures characteristics. This attribute I strongly utilised in the modeling of emission trading.

The future reference scenario was defined by sectoral activity rates. At this point the sectoral results from the ENPEP/BALANCE runs were utilised and the activity rates were thus derived. In the reference scenarios only the scheduled revolution of equipment is considered, no other efficiency measures are incorporated in the results.

Base year was 2005 (fixed start year) which was a practical solution from the aspect of data availability and others. The activity rates, energy carrier usage values and emissions were given for the base year from the National Greenhouse Gas Inventory Report, the National Allocation Plan, other energy statistics and the IPCC emission factors.

The power sector's emissions in 2005 were 16.9 Mt CO_2 (29% of the total domestic emissions), electricity consumption was 42 TWh, while electricity production was 15% lower, 36 TWh. The future activity rates were derived from the MAVIR capacity plan, utilising key figures from the National Renewable Strategy for renewable electricity generation and combined heat and power generation.

Emission scenarios formulated

After the corrections and initialisation, the model was run. I formulated three emission scenarios, first a reference scenario, then a scenario based on existing policies and measures, then finally an emission scenario which showed the technically-economically feasible mitigation potential. The BALANCE results were used for the scenario formulation.

Baseline scenario

The baseline scenario serves as a reference and does not include any climate change mitigation measures: all business proceeds as usual. The scenario is good for comparison with other scenarios including measures. Main assumptions were as follows:
The sectoral activity rates apply, no listed technical measure is implemented in any sector, renewable production stagnates, no efficiency improvement is foreseen in the power sector, energy demand growth is not influenced by any energy efficiency action or measure, thermal efficiency of power plants are according to the HTSOC's capacity plan. Policies and measures already implemented in previous periods are part of the baseline.

"Existing measures" scenario

The scenario which considers measures already adopted and under implementation perhaps is the most important, as this forecast is the most realistic future-line. The scenario considers the impact of policies and measures, among other the base case put down in the Renewable Strategy[11], and it also considers the modernisation and development actions in the respective sectors, and that they result in a decreasing energy intensity in accordance with the NEEAP (1% annually until 2016) targeting the EU goal of reductions. It considers furthermore the Transportation Operative Programmes effect, even though it is mediocre. The scenario also considers the continuation of the EU ETS with the same emission cap as now, due to the lack of further information.

"Additional measure" scenario

The additional measures scenario considers the impact of measures beyond the existing ones, the planned and possible measures are considered, the assumption on renewable penetration is the highest according to the Renewable Strategy, every measure is implemented according to their potentials, the EU ETS further operates, the EUA price is expected to be 24 Euro/t. Mitigation efforts are supported by the government to the fullest economically feasible extent.

Results of the modeling

The forecasted aggregate emissions are shown on Chart 4.7., aggregate data is shown in Table 4.11.

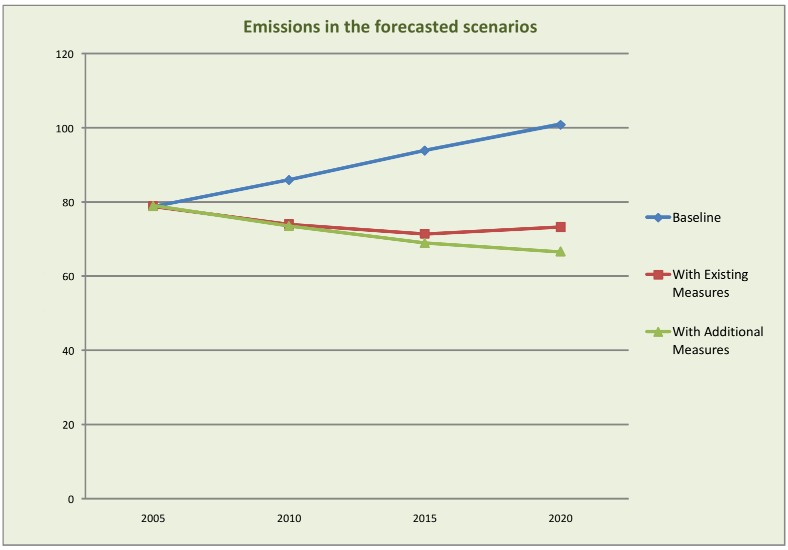


Chart 4.7. Total forecasted domestic emissions.

Source: own calculations

Studying the results on the chart, it is clear that the implementation of domestic measures and policies can reduce emissions on the mid term. This however requires the allocation

[11] http://www.khem.gov.hu/feladataink/energetika/strategia/megujulo_strategia.html

of adequate resources and other incentive measures. The quantitative figures are summarised in Table 4.11.

Table 4.11. Emissions by scenario in the forecasted periods

Greenhouse gas emissions in respective scenarios (CO_2 eq, Gg)	2005	2010	2015	2020
Reference scenario	80382	85914.58	93861.65	100864,8
Existing measures scenario	80382	73949.46	71387.09	73276.39
Additional potential measures	80382	73488,55	68893,89	66561,95

Source: own calculations

Examining the quantitative results in the table, it is visible that domestic measures can significantly (in the range of 7-13 Mt CO_2 equiv.) reduce emissions compared to the base year of 2005, and with 30 Mt CO_2 equiv. compared to the base period of Hungary. For the implementation of the additional measures the quantity of additional savings has to be considered (6 Mt which can be partially monetised in the EU ETS) and the cost required for achieving these savings.

EU Emission Trading System (EU – ETS)
According to the present regulation there is a national cap (approximately 26 Mt/a in Hungary), although the EU bubble is approaching. The difference between domestic emissions from sectors under ETS and the national cap is equalised with emission trading. Sector under ETS show different willingness to abate emissions under different EUA prices as derived from the marginal abatement curves according to Table 4.12.

Table 4.12. Expected sectoral emission reduction at different EU ETS price assumptions

EUA prices assumed	Industry	Industry-CHP	Power sector	Σ
20 Euro / t CO_2	1.922	2.467	0.1930	4.583
24 Euro/ t CO_2	1.922	4.119	0.1930	6.236
30 Euro/ t CO_2	1.929	4.125	0.1930	6.248

Source: own calculations

It is clear that the cheapest options are found in the industry, e.g. the heat production for self-consumption. The other areas are relatively not sensitive to the price, there are no further efficient abatement options at a reasonable cost. If we extend the scope of EU ETS to households and tertiary sector, or we somehow leverage these sectors in the mitigation efforts, then a synergic effect can be achieved. According to the modeling calculations, domestic energy efficiency (demand side) measures can achieve a significant impact in the ETS sectors, as summarised in Table 4.13.

Table 4.13. Impact of energy efficiency improvements additional to the EU ETS (MT CO2 equiv.)

	2010	2015	2020

Estimated impact of energy efficiency measures on ETS	1.1672	1.8679	2.3151

Source: own calculations

Households

The abatement potential of the household sector has to be emphasised. The runs of the HUNMIT model (Chart 4.8.) show that domestic households can achieve 4.5Mt emission savings with negative cost (that is, even at a zero carbon price) by 2020. This shows the malfunction of a subsystem in the economy (assumedly the credit market) which has to be targeted with appropriate state policies (industrial house refurbishment, green investment system, other energy programs). This result underlines similar earlier results emphasising the urgent need for government intervention.

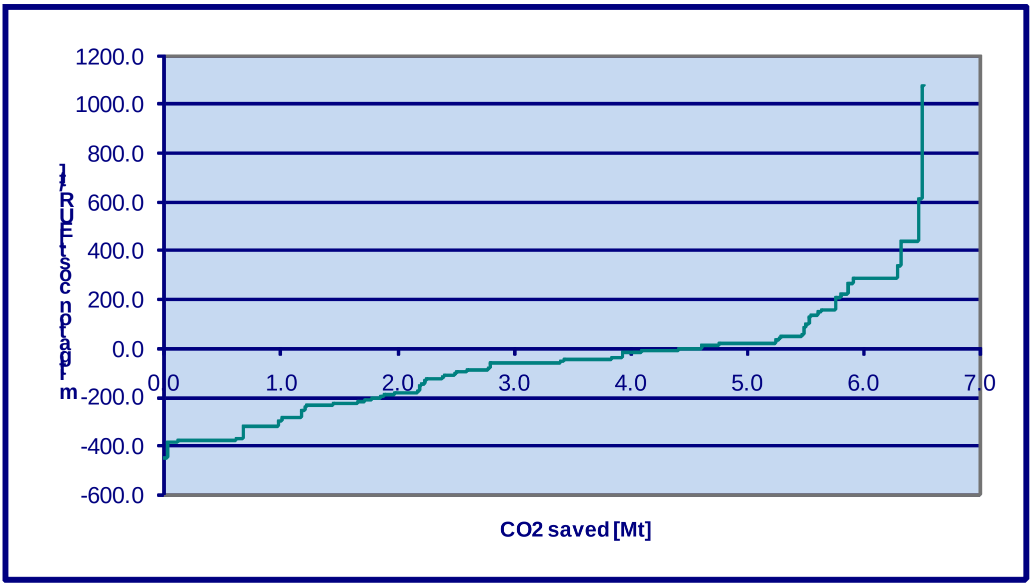


Chart 4.8. Curve of marginal cost of abatement in the household sector(2020)

source: own ed., HUNMIT

Domestic mitigation costs of the Cancun Agreement

The agreement in Cancun is expected to outline a commitment of 30% reduction for Hungary. Although the base year is not clarified, it is expected to be 1990. The domestic greenhouse gas emissions in CO_2 equiv. were 99.2 Mts, the 30% reduction means 30Mt emissions saved until 2020. According to the previous results this can be achieved purely based on domestic measures, the costs however remain to be seen.

The results indicate that the household and tertiary sectors will have to take their share of the commitments, as this is the only way to keep the costs on a reasonable margin.

Results justify the hope that Hungary can take part in fulfilling international commitments efficiently and at a low cost. The economy can be redirected to a sustainable pathway if the necessary measures are implemented.

4. New scientific results

In the dissertation I accomplished the following results.

1. With the aid of statistical analysis it was proven that similarly to international examples, there is a cointegrative relation between time series of energy consumption and economic growth in Hungary. Utilising causality analysis it was shown that economic growth is more likely to Granger-cause energy consumption than vice versa. An energy-extended Cobb-Douglas function was estimated for the domestic after transition context.

2. An alternative approach was given to the macroeconomical analysis with the energy extension of the Solow-model. The assertion of stabile energy consumption level results in the equilibrium capital growth rate to be equal with the savings rate divided by the sum of amortisation rate plus energy efficiency improvement rate. It was shown in the extended model that if energy efficiency can be improved to such an extent that it stabilises the energy consumption, then the macroeconomic output function can be written as the function of capital and energy use only (omitting labor). Furthermore it was shown that economic output can be increased to a higher ($\beta+\gamma$) than expected (β) proportion by improving energy efficiency. This result gives a methodological proof to the conjecture that improvements in energy efficiency can secure economic development without additional energy consumption growth.

3. Based on a game theoretical approach it was shown that preventive action is a reasonable and optimal strategy for a forthcoming energy crisis.

4. A forecast was given for the domestic energy sector adopting and applying a non-linear general equilibrium model. The domestic energy efficiency and energy savings measures potential was demonstrated and presented, together with their significance and sectoral roles. The highest role for these measures was found in the households and tertiary sectors.

5. A forecast was given on domestic greenhouse gas emissions and the domestic mitigation potential. The synergic effects of measures concerning energy and climate change can provide win-win measures. Concerning the households sector it was highlighted that market failures are present and government intervention is necessary to exploit the hitherto not implemented negative abatement cost mitigation measures.

5. Conclusions and recommendations

The question of energy use is closely connected with the sustainability of our economic development level. Though the lack of exact data hinders the proof, nevertheless the application of the proposed game theoretical approach gives sufficient indication that preventive action should be a dominant strategy of the governments.

It was proven in theory that higher end-use energy efficiency is an important and effective tool, and its improvement with the support of the further penetration of renewables can ensure our economic development.

The domestic forecast shows that our energy consumption might reside, but in the transport and tertiary sectors the energy demand is expected to increase. Results clearly indicate that significant savings can be achieved by applying the domestic policies and measures, nevertheless even the most extensive application of measures can not decrease energy consumption to a larger degree.

Consequently our atmospheric emissions also grow in a similar manner, and our concerns about climate change become more and more emphasised.

It can be stated that our oil based economies can not operate further without a radical change. The competition for the remaining oil reserves will push oil prices higher and higher and render the oil nations absolute arbiters of economical and political processes.

Neither our present knowledge nor the results in the dissertation shed light of unambigousity on what is the realistic way out. The priority has to be “delaying”, to win time with energy efficiency and energy savings measures and other governmental actions for the development of sustainable energy solutions. An important task for local communities is the preferential subsidising of efficient, environmentally friendly and emission reducing solutions (e.g. communal transportation). For this however a common agreement has to be reached that these changes are necessary and reasonable, and that the investment will have its socio-economic return in the future. If this happens, the problem of energy scarcity will be coupled with climate change adaptation and mitigation efforts and opens a possibility for a long term solution based on wide consensus. Till this happens, responsible management of energy and crude oil resources has to remain to ensure a sustainable development pathway.

6. Publications

Book or chapter in foreign language

1. Farkasné Fekete M., **Molnár M**. (2010): The role of Hungarian agriculture in implementing climate change policy goals, pp 79-93. *in* Economics of sustainable agriculture (ed. Szűcs I et al.) Scientific Book Series 2010, ISBN 978-963-269-145-9, Gödöllő: Szent István Egyetemi Kiadó, 2010.

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1. **Molnár M**. (2010): Energia, megújuló erőforrások, mitigáció. pp. 29-31. p. *In*: Bozó L (szerk.): *Környezeti jövőkép, Környezet és klímabiztonság*. Budapest: MTA, 63 p., ISBN 978-963-508-567-2

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4. **Molnár M**., Molnár S.: Financing Energy Efficiency and Sustainable Energy Projects in Hungary, *Bulletin of the Szent István University*, Gödöllő, pp. 359-375, 2008, ISSN 1586-4502
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1. **Molnár M**., Molnár S., Tánczos Lné.,.: Hazai klímapolitikai intézkedések értékelése az energiaszektorban, Elektrotechnika, Vol. 103, 12/2010, pp. 5-8, HUISSN: 0367-0708
2. **Molnár M.,** Hazai energetikai üvegházgáz-kibocsátások modellezése nemzetközi beszámolási kötelezettségeink kapcsán, *Acta Agraria Kaposváriensis, megjelenés alatt*

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1. Fekete-Farkas M.– **Molnár M.** –Csábrági A.: Assessment Of Sectoral Greenhouse Gas Mitigation Options And Potentials In Hungary, *in* Proceedings of the International Congress ENERGY AND THE ENVIRONMENT 2010, "ENGINEERING FOR A LOW-CARBON FUTURE", October 18-22, 2010, Opatija, Croatia, (Vol1) 2010, pp. 477-489., ISBN 978-953-6886-15-9
2. **Molnár, M**: Hungarian Experience in Economy of Corporate Energy Efficiency Measures in the Framework of Intelligent Energy for Europe's 4EM – Motor Challenge Project, in *Erdei Ferenc V. Tudományos Konferencia, pp 493-497,* ISBN 978-963-7294-73-0, 2009
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2. **Molnár M.,** Molnár S., Lágymányosi A.: Környezetinformatikai modellek elméleti kérdései és hazai alkalmazásuk az energetikai kibocsátásokban, *Informatika a Felsőoktatásban*, 2008, konferenciakiadvány, Debrecen, 2008, (társszerzők:.). ISBN 978-963-473-129-0, pp 214-215.
3. **Molnár, Márk**: Energetikai modellezési koncepciók és hazai alkalmazásuk az üvegházgáz-kibocsátások területén, in Erdei Ferenc V. Tudományos Konferencia, ISBN 978-963-7294-73-0, pp. 1337-1341
4. Farkasné Fekete Mária, **Molnár Márk**: Fenntartható fejlődés - energiagazdálkodás – klímaváltozás, *in* XII: Nemzetközi Tudományos Napok, Gyöngyös, 2010. március 25-26, ISBN 978-963-9941-09-0, pp. 222-232
5. **Molnár Márk**, Sleiszné Csábrági Anita: Erőművi beruházások költségeinek vizsgálata az EcoSense modell segítségével, *in* XII: Nemzetközi Tudományos Napok, Gyöngyös, 2010. március 25-26, ISBN 978-963-9941-09-0, pp. 233-239

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