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Published in:

Book of Abstracts: 8th CONFERENCE ON SUSTAINABLE DEVELOPMENT OF ENERGY, WATER AND ENVIRONMENT SYSTEMS

Publication date:

2013

Document Version

Peer reviewed version

[Link to publication from Aalborg University](#)

Citation for published version (APA):

Pukšec, T., Mathiesen, B. V., Novosel, T., & Dui, N. (2013). Energy demand modelling and GHG emission reduction: case study Croatia. In Book of Abstracts: 8th CONFERENCE ON SUSTAINABLE DEVELOPMENT OF ENERGY, WATER AND ENVIRONMENT SYSTEMS. (pp. 111). Faculty of Mechanical Engineering and Naval Architecture, Zagreb.

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Energy demand modelling and GHG emission reduction: case study Croatia

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ABSTRACT

In the light of new European energy-climate package and its measures for increasing security of supply, decreasing the impact on environment and stimulating sustainable development with special emphasis on job creation and regional growth, Croatia as a future EU member state, needs to reconsider and develop new energy policy towards energy efficiency and renewable energy sources, in order to comply with all of the presented tasks. Planning future energy demand, considering various policy options like regulation, fiscal and financial measures, becomes one of the crucial issues of future national energy strategy. This paper analyses Croatian long term energy demand and its effect on the future national GHG emissions. For that purpose the national energy demand model was constructed (NeD model). The model is comprised out of six modules each representing one sector, following Croatian national energy balance; industry, transport, households, services, agriculture and construction. For three of the modules (industry, transport and households) previously developed long term energy demand models were used, while for the remaining three new models were constructed. As an additional feature, new GHG module was assembled and added to the NeD model covering all six sectors and calculating its emissions. The model is based on bottom up approach, where data was available, which combines and process large number of input data at the end use level. NeD model was used to present different future GHG mitigation paths, based on the implementation of various energy policies. Results obtained in this paper were also compared to Croatian National Energy Strategy for the years 2020 and 2030. It was shown that if already implemented policies are properly taken into account the actual final energy demand for 2030 will be 43% lower than forecast by the Croatian National Energy Strategy.

Key words: energy planning, future energy demand, GHG emissions, energy policy

1. Introduction

Croatia has experienced a steady growth of energy demand up until 1990 with a peak of 275.67 PJ in 1987 [1]. Industry consumed 38% of the final energy at that time, transport 20% and other sectors combined the remaining 42% [1]. Following the collapse of the Republic of Yugoslavia and the ensuing war, Croatia's industry was devastated and the overall energy consumption, especially in the industry sector, experienced a substantial decline. The transport and other sectors began to recover and the energy demand started to increase again. As a result of this the total final energy consumption reached the pre-war levels by 2010 [1]. The industrial sector however never recovered. The energy consumption of Croatia's industry remained at the post-war level until 2008 when it experienced another drop caused by the European wide recession. Figure 1 shows the final energy consumption of the industry, transport and other sectors in Croatia from 1985 till 2011.

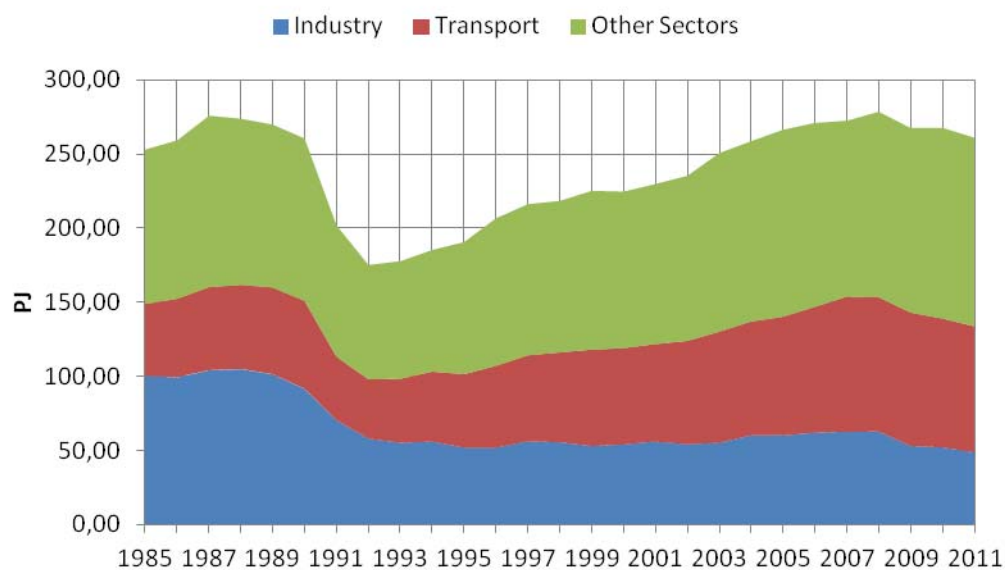


Figure 1 Final energy consumption by sectors in Croatia [1]

In order to analyse Croatia's final energy demand and construct its long term energy demand forecast, NeD model was constructed. The model is comprised out of six economic sectors; households, industry, transport, services, agriculture and construction sector. The development of the model was done through few stages, where each stage presented a detailed long term energy demand model of one economic sector. Since every previously developed model was constructed in MS Excel tool, their synthesis was fairly easy. The final stage in the construction of the NeD model was the creation of a GHG emission mode that unifies and covers all six sectors.

Generally, energy demand planning can be done by two main philosophies; top down and bottom up approach [2] [3]. In order to construct all six economic sectors bottom up approach was used. NeD model presents a highly detailed model whose main purpose is to show how future energy demand is influenced by various mechanisms. Engineering bottom up energy demand models, which focuses on end users, usually can have a better overview and evaluation of potential future energy savings. This feature is crucial in order for the new energy policies and strategies to be made and tested [4]. Downside of this approach is an extensive input data that has to be gathered and systemized [5] [6].

Classical energy demand planning is usually focused on establishing relationship between economic variables such as GDP and energy consumption. This is usually done based on different historical data. If we compare the primary energy consumption and the growth of GDP, it is visible that in Croatia's case these two factors are still linked. The increase of the GDP is followed by the increase in energy demand up until the late 2000s when the country experienced a crisis lowering the GDP and as a result the energy consumption has decreased as well [7]. Figure 2 presents the GDP and the primary energy consumption for Croatia for the period from 1992 till 2010. Decoupling economic growth and energy consumption is possible. Figure 3 shows the same data for Denmark. It can be seen that Denmark has successfully decoupled their increase in GDP and energy consumption. This means that Denmark has increased its overall energy efficiency while Croatia still has to achieve this.

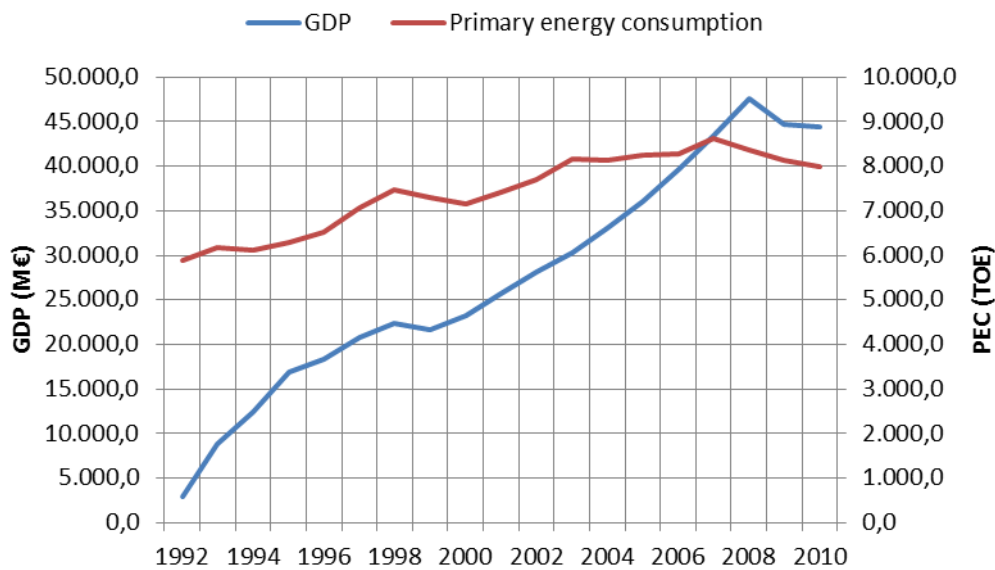


Figure 2 GDP growth and primary energy consumption in Croatia [7]

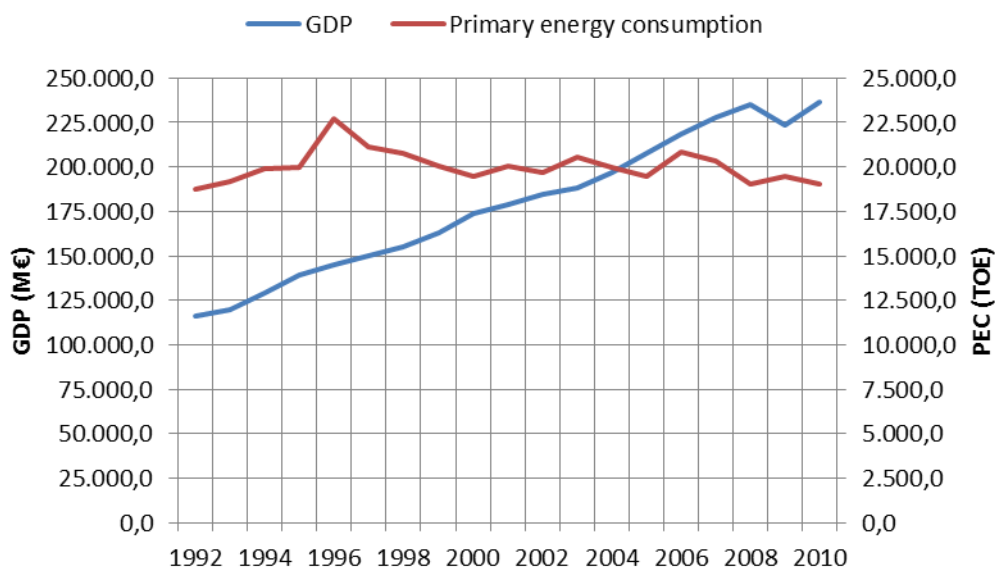


Figure 3 GDP growth and primary energy consumption in Denmark [7]

One of the intentions of NeD model is to decouple economic growth from the energy consumption and focus on different energy policies as main driving parameters influencing future energy demand.

NeD model presents a valuable tool which can be used for the integral energy planning process. Forecasting future energy demand is a starting point for any future advanced system analysis where energy demand data presents a key input parameter [8] [9]. NeD model can support supply side oriented energy planning models and tools in more accurate energy system analyses [10] [11].

Similar long term energy demand models were tested in order for their advantages and planning methodologies could be assessed. The two most interesting ones being LEAP and MAED-D. LEAP presents a good accounting energy demand/supply model with advantage in being easy to use and data not so extensive [12] [13]. At the same time it doesn't present the level of details if compared to NeD model. The main disadvantage of accounting models, including NeD model, is their inability to perform any type of optimization that could result in the least costly solution. Second bottom up energy demand model tested on Croatia as a case study was MAED-D. In this case model is not user friendly and it requires detailed and specific input data which can be difficult to obtain [14] [15]. Second disadvantage of MAED-D is its inability to modify model structure which can be very interesting and useful in some cases.

This paper is structured as follows; in the methodology part overview of all six economic sectors will be presented. Long term energy demand models for the households sector, industry and transport have already been published by the author, so here they will be referenced and very briefly explained. The remaining three sectors will be covered in a more detailed way since they have been recently constructed specially to be incorporated into the NeD model. Final section of the methodology part will focus on the GHG emission calculation methodology. Through results paragraph most interesting findings will be presented and discussed and finally main conclusions will be given.

2. Methodology

One of the biggest advantages of the NeD model is its ability to model various energy policy scenarios through endogenous parameters. This allows more accurate calculations when energy demand forecasts are made. NeD model is constructed from six individual energy demand forecast models all based on bottom up approach. They all work by calibrating its methodology on one reference year which is chosen by the user. In the following paragraphs main equations and logics of each sector will be presented as well as the final part of the NeD model, which is the GHG emission mode.

1.1 Households sector

NeD households sector is constructed by importing and adopting HED methodology, developed previously for the Croatian households sector [16]. Figure 4 presents the main logics in calculating future energy demand. In order to calculate heating and cooling demands as well as energy needed for cooking, hot water and electronic appliances population and available floor surfaces needs to be calculated. All demands, except electronic appliances, are

first calculated at the useful energy level. Afterwards, in the fuel mix mode useful energy is transferred to final energy level, combining different technologies and market shares.

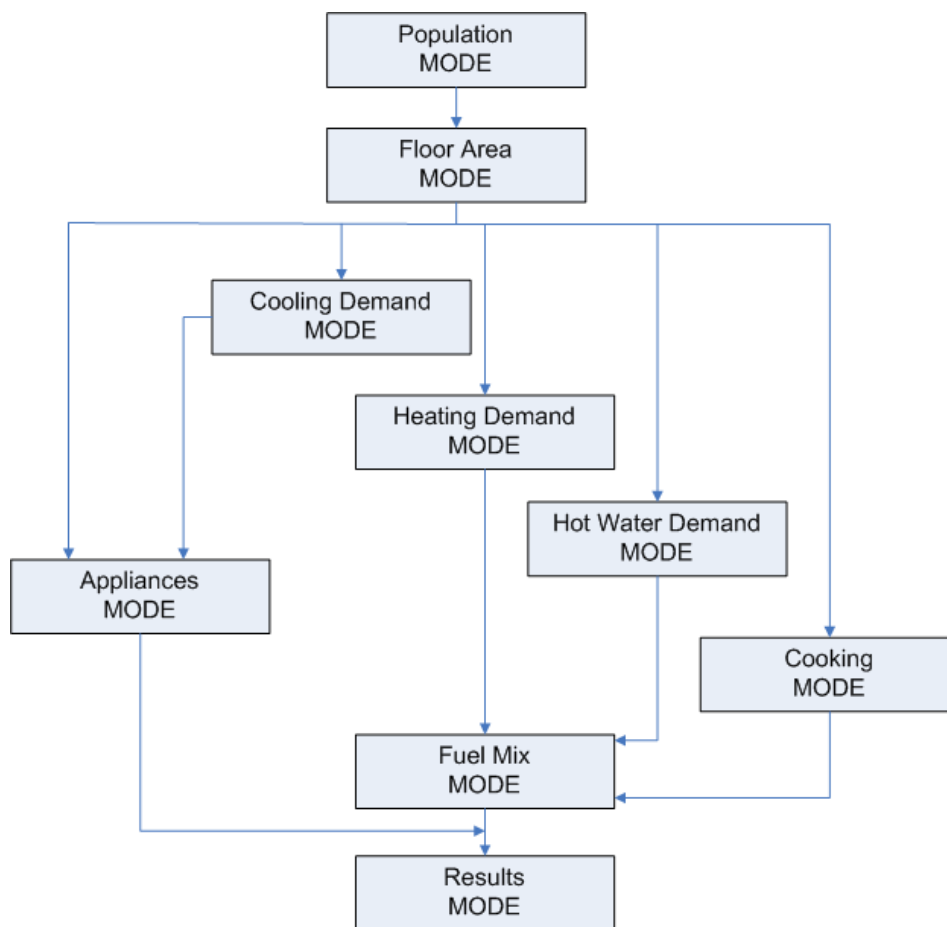


Figure 4 Overview of the households energy demand calculation

1.2 Industry sector

NeD industry sector is constructed by importing and adopting IED methodology developed previously for the Croatian industry sector [17]. There are four major parameters, when it comes to energy demand projections, covered through this methodology. Special focus is given to export /import component which determines the ratio of domestic production capacities resulting in changes in energy demand. Phasing out or introducing certain type of industry also plays an important role because these changes can significantly influence the energy demand and the best example of phasing out is the textile industry which has almost completely disappeared in Croatia. Technology and efficiency component is considered in order to examine the influence of technological advancements on future energy demand. General structure and logics for calculating industry energy demand is presented in Figure 5. The last major parameter is the fuel mix which provides the opportunity to further improve the future energy demand according to assumptions related to phasing out of some fuels and adding new more environmentally friendly alternatives as well as renewable energy sources. All four parameters are tested in the reference year in order to verify the suggested methodology which will be used later on for future energy demand predictions.

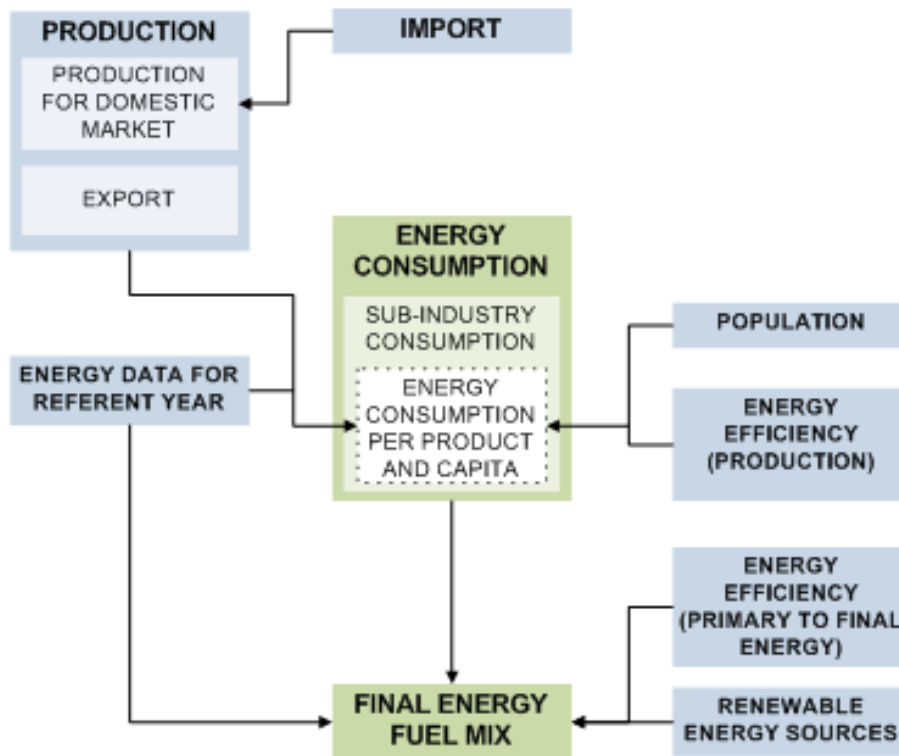


Figure 5 Overview of the industry sector energy demand calculation

1.3 Transport sector

NeD transport sector is constructed by importing and adopting EDT methodology developed previously for the Croatian transport sector [18]. The methodology is based on the principle of covering and analysing every subsector (road, rail, sea and river, air and public transport) separately and then summing their contributions in the final energy demand balance. A cross-subsector connection only occurs when calculating the modal split between road, air and rail transportation. Every subsector is quite specific in the energy demand calculation procedure but one unified note can be identified. Calculations are based on the number of end users (vehicles, trains, buses, aircrafts etc.), their efficiency, usage, availability etc. First, all statistical data needs to be imported into the model to initiate the necessary calculations. Afterwards, based on the reference year, all missing and unavailable parameters can be calculated and tested which is a main condition before starting to predict future energy demand. Users can set different scenarios that could show and quantify how different energy policies influence future energy demand. General overview of the methodology and calculation procedure can be seen on Figure 6.

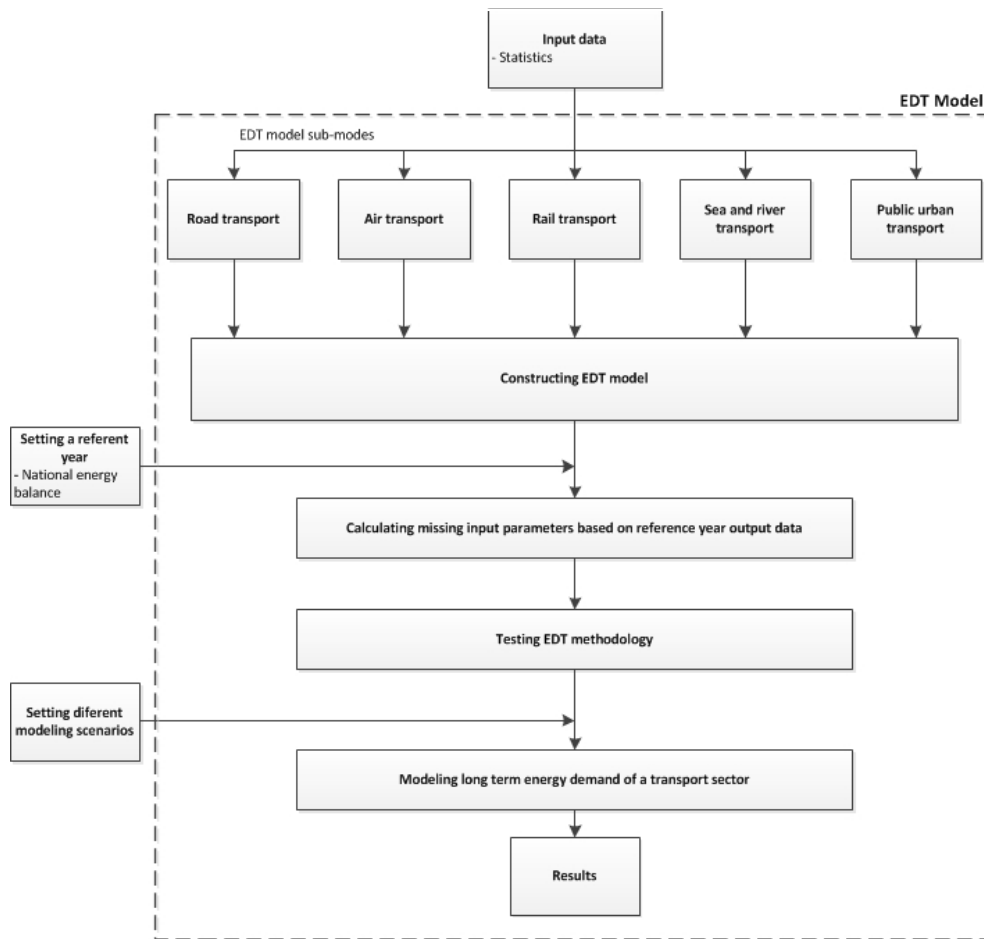


Figure 6 Overview of the energy demand planning methodology of a transport sector

1.4 Services sector

Calculating final energy demand of the services sector is done by summarizing all subsectors and their final energy demands. Available subsectors are: education, tourism and catering trade sector, health, commerce and government. The main focus is given to tourism and catering trade sector since in this case the most activity has been assumed. Base on that assumption individual model has been developed [19] whose methodology and calculation procedures were implemented into the NeD model. For the rest of the service subsectors HED methodology was applied but with adjusting certain parameters in order to capture all the specifics. Geographic distribution during calculation procedures is not set to the county level, like in the HED model applied to households, but at the regional level; southern, east and north-west Croatia. Available floor area is modeled based on the specific available surface per capita for different kind of services:

$$A_{i, \text{spec}}^f = B_i^f / P^f \text{ [m}^2\text{/capita]} \quad (1)$$

Energy demand of the health subsector is calculated for 10 different categories;

- Hospitals
- Institutes of public health
- Clinics
- Health centers
- Pharmacies

- Care organizations
- Other health institutions
- Health companies

Energy demand of the education subsector is calculated for 4 different categories;

- Kindergartens
- Primary schools
- Secondary schools
- Universities

Energy demand of the commerce subsector is calculated for 5 different establishments depending on the number of employees. Based on this information square meters and volume could have been calculated. Chosen categories are:

- Establishments with 0-9 employees
- Establishments with 10-19 employees
- Establishments with 20-49 employees
- Establishments with 50-249 employees
- Establishments with 250+ employees

For the government subsector, the same categorization is made as for the commerce subsector with difference in considering different specific floor areas.

1.5 Agriculture sector

The agricultural sector represents approximately 4% of the Croatian final energy consumption with 10.27 PJ in 2010 [1]. Even though this isn't a very substantial amount, the agricultural activity is an important aspect in the country. Because of that, special care has to be taken when the system is modelled and when predictions are being made. In order to recreate the energy consumption of the sector it was first divided into agriculture and animal husbandry. Both subsectors were then further divided into family farms and industrial farms and then further on into specific production (corn, wheat, barley and so on for agriculture and cows, pigs, sheep and poultry for animal husbandry).

The energy consumption of the agricultural production is calculated according to the equations 2 and 3:

$$EI_a = E_a / P_a \quad (2)$$

$$EC_a = EI_a \cdot CP_a \quad (3)$$

The energy consumption of animal husbandry is calculated according to the equation 4:

$$EC_{ah} = EI_{ah} \cdot NOE \quad (4)$$

Historical data for the production of specific crops and the raising of certain animals were taken into account as well as the ratio between small family and larger industrial farms. The calculated results were then compared to the data obtained from [1] and the difference between the two turned out to be negligible.

1.6 Construction sector

Although not usual in energy planning, construction sector is included into the NeD model. Primary reason for this is to follow the national energy balance and national statistics and allow similar future studies to compare NeD results. Construction sector is usually included into the transport or industry sector when calculated with similar models. Energy demand model for calculating the construction sector is based on the national statistic which covers 6 main energy consumption categories; residential, non-residential, transport infrastructure, pipelines, communication and electricity lines, complex construction on industrial sites and other civil engineering works. For every of the 6 mentioned categories fuel mixes were calculated; LPG, diesel, gasoline, electricity, heavy oil and renewables. The main calculation procedure is as follows:

$$F_{ij}^z = L_{ij}^{z, spec} \cdot C_j^z \quad [\text{PJ}] \quad (5)$$

Equation 4 represents the main calculation procedure for each fuel type in each energy consumption category. With i representing the fuel type and j representing the energy consumption category (residential, non-residential etc.). Based on the energy consumption category units for the $L_{ij}^{z, spec}$ and C_j^z are determined. If the calculation is made for residential and non-residential the units used are $[\text{PJ}/\text{m}^2]$ and $[\text{m}^2]$. In case of other four energy consumption categories units used are $[\text{PJ}/\text{construction site}]$ and $[\text{number of construction sites}]$. Cross connection of NeD model is visible through energy demand calculation of residential and non-residential energy consumption categories. All the newly build available floor surface that are calculated in the households and services sector are imported into construction sector model as an input data. Based on this data energy needed for constructing all those new floor area is calculated.

1.7 GHG emission mode

Current version of the NeD model calculates only CO_2 emissions from all six economic sectors. This is done by importing calculated fuel mix into the GHG mode. Afterwards conversion factors, needed for the calculation of the GHG emissions, are set by the user. Model then calculates CO_2 emissions generated from every fuel type. Basic principle of GHG calculation can be presented by the following equation.

$$G_i^z = S_i^z \cdot K_i^z \quad [\text{tCO}_2] \quad (6)$$

Where i presents the fuel type for which the emitted CO_2 is calculated while the conversion factors are set basically depending on the fuel observed.

3. Results and discussion

Through this paragraph main results calculated by NeD model will be presented. Since most interesting results and scenario options have already been presented for households, industry and transport sector, here, the focus will be on the remaining sectors and to whole country's final energy demand and GHG emissions. On Figure 7 four different scenarios of the Croatian services sector can be seen. First scenario is the one with the frozen efficiency while

the following three are represented with three different yearly renovation rates. If comparing the two most extreme scenarios, frozen efficiency and 3% renovation rate, energy demand in the year 2050 could be 28% lower.

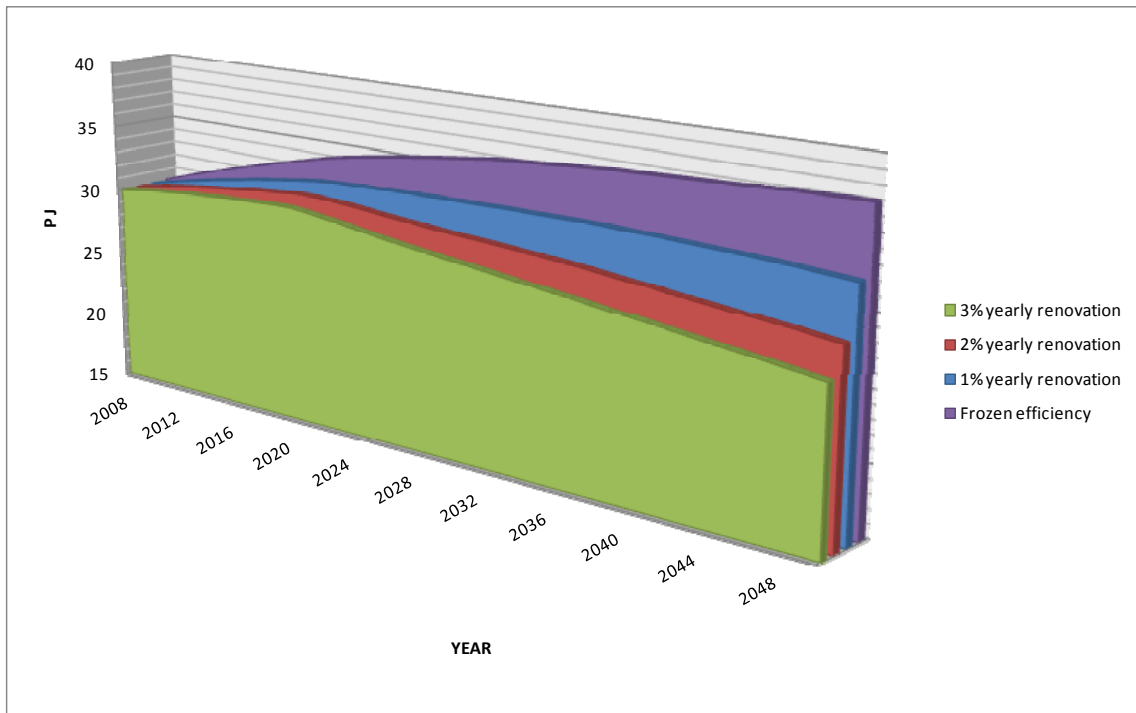


Figure 7 Long term energy demand scenarios of Croatian services sector

On Figure 8 one of the energy efficiency scenarios of the construction sector can be seen. Unfortunately due to the specifics of the work required and technologies available which are closely connected to heavy machinery, this sector is expected to stay heavily dependent on liquid fossil fuel. One of the possibilities is a graduate switch to biofuels which can be expected in the future.

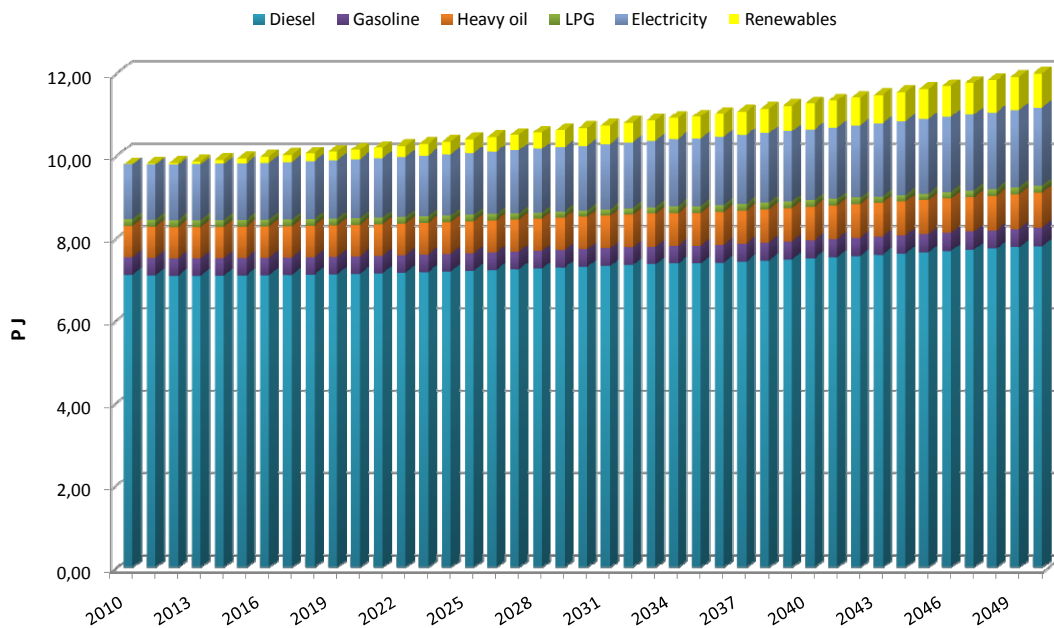


Figure 8 Long term energy demand scenarios of Croatian construction sector

Although agriculture, as well as construction sector, are not so relevant when comparing it to the total national final energy demand they are still interesting to analyze. One of the key elements in the future agriculture production will be the efficiency of the agriculture process itself. From one side increase in energy efficiency of the machinery is important but from the other side land concentration will play a key role in increasing future agricultural production. Currently agricultural production in Croatia is characterized by many small estates. Their cultivation presents a large dissipation of energy.

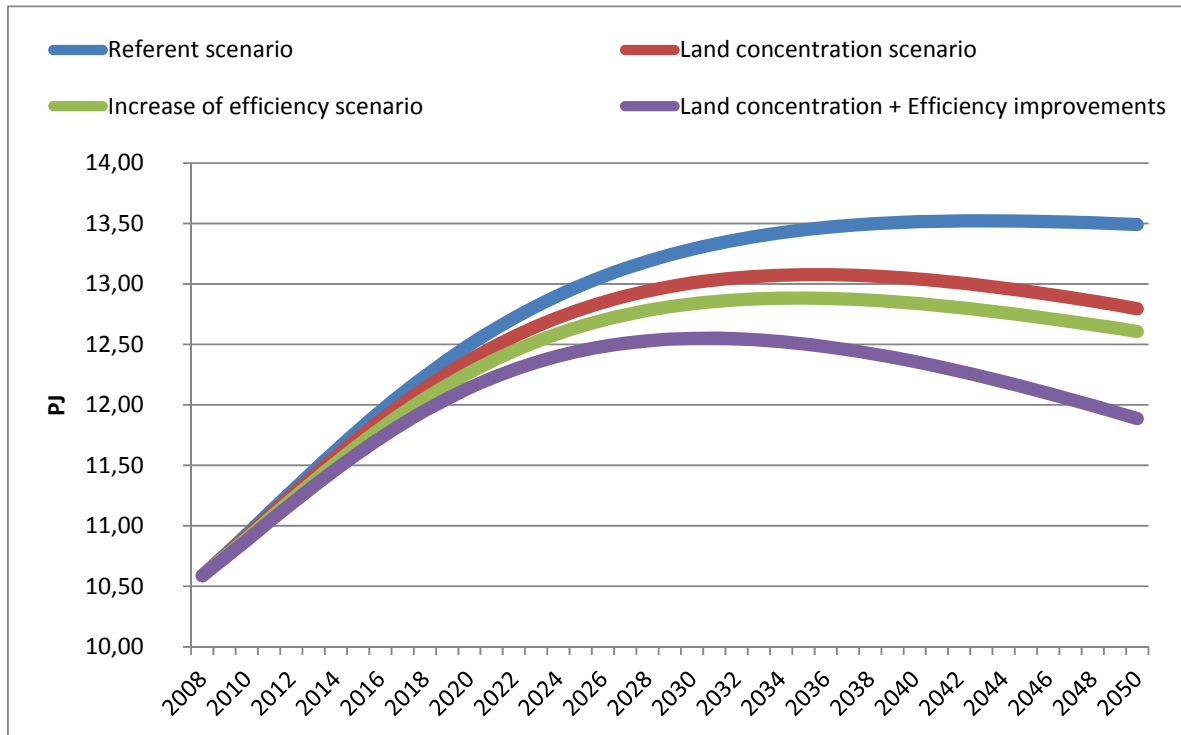


Figure 9 Long term energy demand scenarios of Croatian services sector

One of the key features of the NeD model is to show energy efficiency wedges for the whole country. Figure 10 shows potential energy efficiency wedges for three main and most important economic sectors. The analysis has shown that the potential energy savings can go up to 157 PJ in the year 2050.

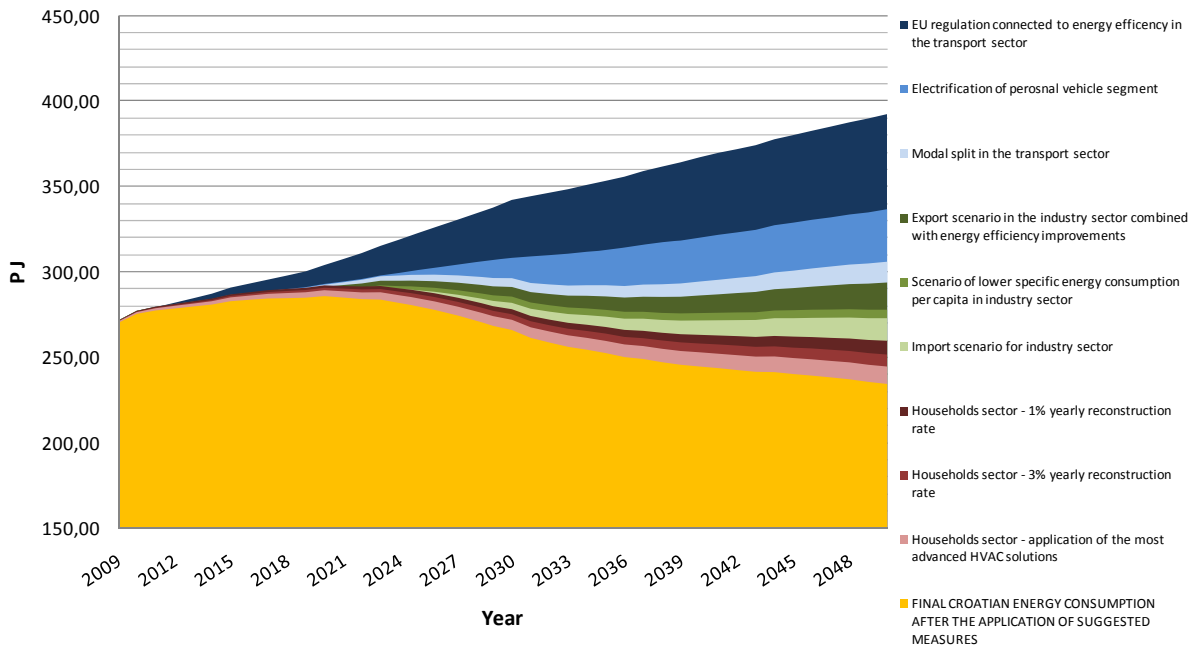


Figure 10 Possible energy efficiency wedges calculated with NeD model

The energy demand scenario colored yellow on Figure 10 (FINAL CROATIAN ENERGY CONSUMPTION AFTER THE APPLICATION OF SUGGESTED MEASURES) is presented in a more detailed way on Figure 11. As expected main energy savings are achieved in the households and transportation sector.

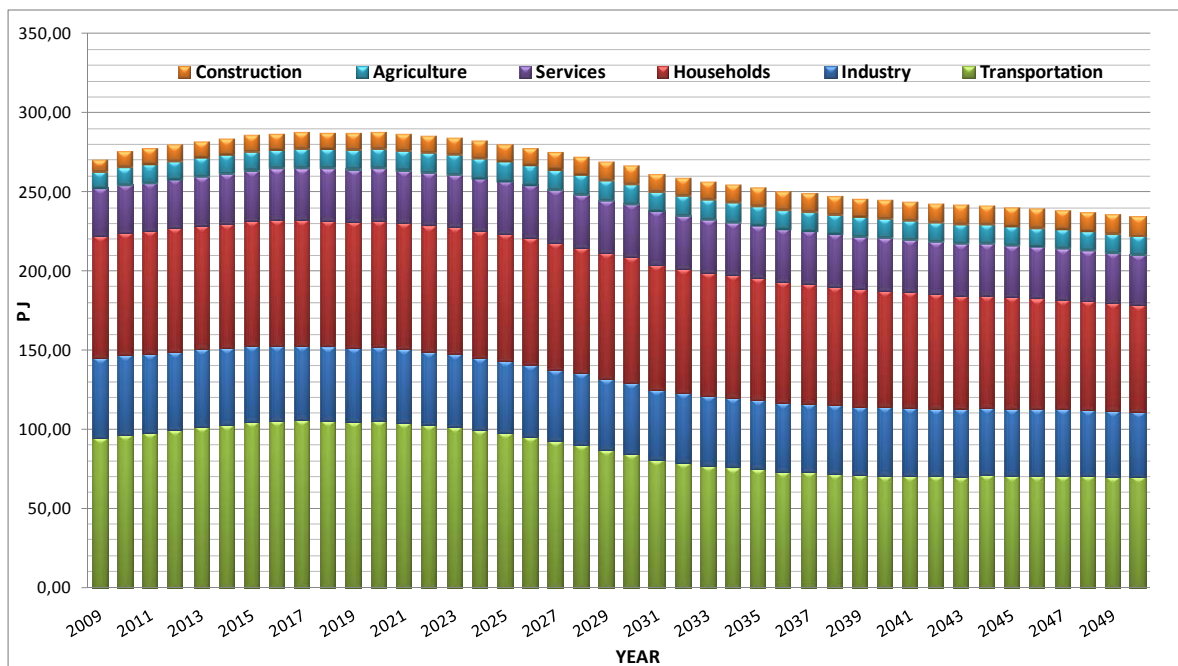


Figure 11 Energy efficiency scenario calculated with NeD model by implementing energy efficiency wedges suggested on Figure 10

After all sectoral energy demands and fuel mixes are calculated they are imported into the GHG mode which is used in calculating CO₂ emissions for every energy demand scenario.

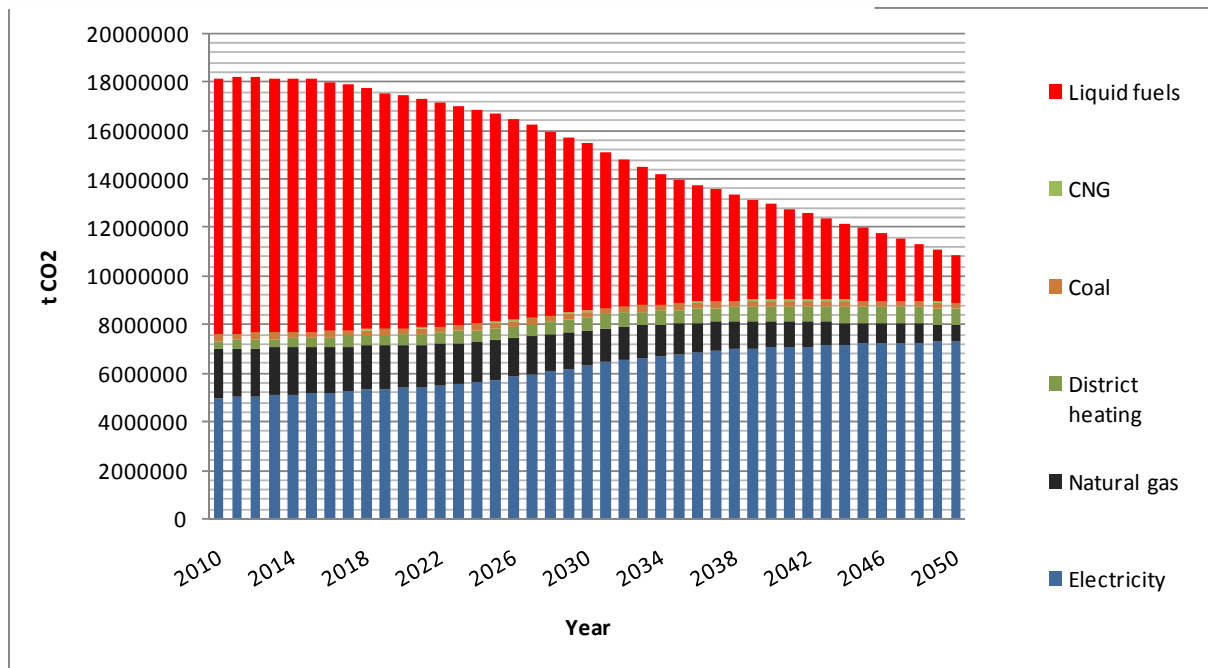


Figure 12 CO₂ emissions of the energy efficiency scenario calculated with the NeD model

Based on the high intake of renewables and through most of the sectors which is followed by high electrification process, also through most of the sectors, CO₂ emission can be reduced substantially till the year 2050 on the level of final energy. If comparing the year 2010 and 2050 significant CO₂ reductions can be achieved with careful and rational energy demand planning. NeD model calculated 38% lower CO₂ emission in the year 2050 if compared to 2010.

4. Conclusion

NeD model presents a unified energy model that can be used for the analysis of a whole country's final energy demand. Its methodology is applicable to any other country under the condition that all local specifics would be described and quantified through the model. In the case of Croatia, results calculated by NeD model show significant energy demand reduction potentials as well as GHG emission potentials in the forthcoming long term period. Transport sector as well as buildings presents the biggest potential in energy demand management, which is fairly expected. If analysing energy efficiency scenario calculated with NeD model, after all the suggested energy efficiency wedges are implemented, energy demand in the year 2050 can be lower more than 16% if compared to the year 2010.

5. Nomenclature

$A_{i, year}^z$ - specific available surface of a certain category of a subsector in a specific year (eg. hospitals, schools etc.) [m²/capita]

$B_{i, year}^z$ - available floor area of a certain category of a subsector in a specific year (eg. hospitals, schools etc.) [m²]

P^z - population in a specific year

z - year for which the calculation is done

EI_a - Energy intensity of the agricultural production of a specific crop (MJ/t)

E_a – Energy intensity of the agricultural production of a specific crop (MJ/ha)

P_a – Crop productivity (t/ha)

EC_a – Energy consumption of the agricultural production of specific crop (MJ/year)

CP_a – Crop production (t/year)

EC_{ah} – Energy consumption of animal husbandry for a specific kind of animal (MJ/year)

EI_{ah} – Energy intensity of animal husbandry for a specific kind of animal (MJ/animal)

NOE – Number of animals (animal/year)

F_j^E - yearly energy demand of a different fuel type for a certain energy consumption category [PJ]

$L_{ij}^{E, spec}$ - specific energy consumption of a different fuel type for a certain energy consumption category [PJ/m²] [PJ/construction site]

C_j^E – yearly property of a certain energy consumption category [m²] [number of construction sites]

G_i^z -yearly amount of CO₂ emitted from specific fuel type [tCO₂]

S_i^z -specific CO₂ emission conversion factor of a certain fuel [tCO₂/GJ]

K_i^z - yearly amount of various fuel consumed [GJ]

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