INTRODUCTION

The paper is focused on an example of unified electricity and gas distribution network long-term planning in a low-density rural region. Planning criteria and possible advantages of such a simultaneous electricity and gas network planning are elaborated.

Special emphasis is given to description of methods and tools used for present energy balance analyses, long-term energy consumption forecast and optimal network topology planning. GIS oriented software is used for energy balance and future consumption forecasting, as well as for unification of electricity and gas network planning.

BASICS OF REGIONAL ENERGY PLANNING

The term “distribution network” refers to the network both in and between towns and settlements, so that we are actually dealing with gas and electricity distribution regional network planning. In the regional organization of a country the regions are most often set as provinces, counties, etc.

The entire procedure is based on the much broader concept of regional energy planning. Regional energy planning is a methodological procedure, with a capacity to encompass all regional specificities and to devise a concrete long term energy development plan of the area. Such planning becomes necessary in the framework of sustainable development planning of a society, when it is necessary to include into the plan both renewable energy sources and possibilities of energy demand reduction through demand side management.

As a matter of fact, regional planning is, by its methods, a form of Integrated Resource Planning (IRP) on regional (local) level. Its core part is the determination of viable development of distribution systems of network energy products. The potential renewable energy sources and possibilities of energy demand reduction are included in the plan in extent in which they enable avoiding of costs. If the environment is treated as a resource, then the structure of distribution systems gives preference to environment friendly energy products, especially renewable sources and electricity demand reduction.

This paper presents the procedure of regional energy planning at the extent of distribution network planning of network energy products - natural gas and electricity. Methodological concept of this core part of the regional energy planning is presented on the Figure 1.

Regional planning starts with taking into account the impact of economic and social development on long term heat energy demand and non-heating energy demand by sectors of consumption. Economical and social impacts taken into account are growth and structure of the regional economy, especially industry, population growth, housing, and service sector premises development, standard of living and purchase power growth, etc. Also, at the very beginning of the procedure it is necessary to have a regional energy balance. If households make a significant share in energy consumption, as well as non-network energy products, such as fuel oil, liquidated fuel gas, or fuel wood, it is necessary to conduct the survey of households in one segment of the region in order to reconstruct the regional energy balance in the base year.

The segmentation or dividing region in zones is carried out in accordance with economic, climate and traditional characteristic of some areas within the region. Such surveys conducted in Croatia showed excellent results, in sense of significant differences in terms of demand and actual energy consumption by average household of a specific zone.

Figure 1 – Methodological concept of the regional energy planning
Additionally to the mentioned initial values the application of end-use method (MEEDE methodology) makes also possible to foresee long term heat demand and non-heat electricity demand. Forecasts by zones enable locating future energy demand in towns and settlements, and by sectors of consumption in each of towns observed: households, industry, services and agriculture. Foreseen heat energy demand represents a potential market for each competitive energy product.

Further procedure of defining the county energy plan starts from plans for gas and electricity distribution network development. The basic rule of gas network planning is that the gas network is brought to consumers only providing it is economically viable. Economic viability is a function of investment and demand development materialised in the investment (i.e., revenues realised by meeting such demand). As the growth of heat demand in zones and sectors has already been determined, it is still necessary to work out the possible natural gas penetration dynamics. Survey gives the insight into a series of influential values. In addition, a more active distributor’s approach to the consumers ranging from promotion to financial support can speed up the penetration of natural gas to the potential heat market.

The basic difference between electricity and gas distribution network planning is the fact that electricity is in principle regarded as a sort of public service, available in almost every part of the country. Therefore the planning of electricity distribution network is based on the least cost principle. In practice that means maintaining electrical energy delivery to the present and new customers with required quality for the lowest amount of investment and operating costs.

Joint gas and electricity distribution network planning is based on different regional gasification scenarios and adequate electricity consumption in towns and settlements, as a function of areas and degree of gasification of the region. This procedure is comprehensive and enables the joint planning of two network systems, which enables corresponding development of network infrastructure in the region.

In cases of so far analysed regions of Croatia we deal with significant substitute of heat related electricity consumption with natural gas in the parts of the region in which the gas can be distributed with economic sustainability. The whole procedure and results are described on the example of Baranja region.

**ENERGY CONSUMPTION ANALYSES**

The necessary condition for both energy balance modelling and future energy consumption planning is to establish the model of space distribution of thermal (fuel and electricity) and non-thermal electricity requirements. This is where GIS oriented tools, applied to the adequate extent, become crucial.

**Energy consumption in households**

Energy consumption in households is influenced by a lot of different geographical, infrastructural, urban, social and other factors. Therefore the Baranja region was divided into 4 zones. The only larger settlement – town of Beli Manastir – was divided into 2 zones: zone 1 – apartment buildings and zone 2 – family houses. Zone 3 is formed by four larger settlements (Bilje, Darda, Mee i Kneževi Vinogradi) with some urban and social characteristics of urban or suburban settlements, and zone 4 includes all other settlements with explicit rural characteristics.

The survey was conducted in the representative sample of 3% of households and included around 70 questions regarding energy consumption and related social and economic aspects, which directly or indirectly influence it. All the data is processed and analysed in MS Access database. The result was specific yearly energy consumption for heating, preparation of hot water, cooking and non-thermal electrical energy consumption for every type (zone) of households. Based on the data on number of households and citizens in all settlements in the region, total useful energy consumption in households in the base year was modelled. The total thermal energy consumption in households in the base year was 210 GWh, out of which 22% (relatively high share) was thermal usage of electrical energy.

**Energy consumption in services**

Sector of services was divided into a few sub sectors depending on the ways of energy consumption: education, tourism (hotels, restaurants, …), trade, administration and government, health care, traffic and the rest unspecified services. For every group a special questionnaire of around 30 to 40 questions was prepared. The survey was conducted on the representative sample of 20% of service related clients. Similarly to households, all the data is analysed and the results were specific yearly energy consumptions of thermal energy (for heating the premises, heating the water and cooking) and non-thermal electrical energy (for different electronic devices, lighting and cooling).

Total energy consumption in services was about 1/10 of the total energy consumption in households (20 GWh).

**Energy consumption in industry and agriculture**

For these sectors of energy consumption the most detailed questionnaire was prepared. The most important part are questions regarding monthly thermal energy consumption for low and high temperature processes and electrical energy for mechanical processes. Besides those basic questions, energy
consumption for heating and cooling the premises, preparation of hot sanitary water and similar secondary use of energy was also included. According to the total number of industrial and agricultural consumers and their yearly electrical energy consumption the representative sample for the survey was determined. 53% of industrial consumers and 24% of agricultural consumers were successfully processed.

There are two major types of industry in Baranja region: machinery and food processing industry. Total thermal energy consumption in industry is 21 GWh. Non-thermal electrical energy consumption is in industry is 11 GWh.

Total thermal energy consumption in agriculture is 4.3 GWh and non-thermal electrical energy consumption in agriculture is 3.5 GWh.

**Total energy consumption in the base year and forecast in 20 year period**

Total final energy consumption, as shown on the Figure 2 and Figure 3, will rise from 299 GWh in the base year to 480 GWh in the end of the 20 year time planning period.

Electrical energy share in the total final energy consumption is relatively high 32%. Even more significant is the amount of thermal electrical energy consumption: even 55% of the total electrical energy consumption is used for thermal purposes.

<table>
<thead>
<tr>
<th>Year</th>
<th>Base Year</th>
<th>Year 5</th>
<th>Year 10</th>
<th>Year 15</th>
<th>Year 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final Energy (GWh)</td>
<td>299</td>
<td>310</td>
<td>320</td>
<td>330</td>
<td>340</td>
</tr>
</tbody>
</table>

### ELECTRICITY AND GAS DISTRIBUTION SYSTEM MODELLING

Existing electricity distribution system in Baranja region, analysed in this paper, consists the following elements:
- one 110/35 kV substation (Beli Manastir),
- four 35 kV lines in Baranja region and two 35 kV lines connecting it to the town of Osijek,
- five 35/10 kV substations with 28 10 kV feeders (Beli Manastir 7, Bilje 7, Kneževi Vinogradi 5, Branjin Vrh 5 and Draž 4),
- total of 336 km of 10 kV lines,
- and 277 10/0,4 kV substations.

Technical and economical optimisation and long term planning of electricity distribution system was conducted with PRAO software developed in the EDF Company. Detailed analyses available in this software require a lot of data: basic network topology, types of lines, rated powers of transformers, load characteristics of consumers, data about reliability, outages and network operation, rated voltage level of 10 kV network elements (lines and substations) – 12 kV or 24 kV. The last set of data is especially important for the long term planning, because it determines the “readiness” of the network to shift from the operation on 10 kV voltage level to 20 kV. All those data were collected in a MS Access database connected with GIS tools (AutoDesk Map and ArcView). The bases for geographical presentation of the distribution network were topographic maps of Baranja region in scales of 1:100 000 and 1:25 000 as well as maps of towns and settlements in scale of 1:5 000. Specially designed subroutine
enables transfer of the data into PRAO format, which is especially useful in cases where some or all of required data is available in some sort of electronic database. The electricity distribution network of Baranja region in PRAO software is shown on the Figure 4.

Figure 4 – Baranja region electricity distribution network in PRAO

Gas distribution system in Baranja region currently does not exist. While the investments electricity distribution system will be mainly focused on reinforcements and reconstructions of the existing objects, the gas distribution system has to be constructed from the transport system to street pipelines and connections to every consumer.

Conceptual project of the Baranja gas distribution system is developed on the basis of the same topographic maps as the electricity distribution system in the ArcView software. All the topology data and the results of hydraulics calculation were arranged in the MS Access database and connected with the GIS project, enabling simple and effective analyses and processing for further economic analyses.

Baranja gas distribution system is planned to be connected to transport system through two pressure regulation stations (Beli Manastir and Mece), where the pressure of the transport system is regulated on the pressure of the distribution system (3 bar).

The example of the gas distribution project is shown on the Figure 5. It is the network in the town of Beli Manastir and the plan of streets is clearly visible.

Figure 5 – Beli Manastir gas distribution network

GAS DISTRIBUTION NETWORK PLANNING

The gas distribution system was technically evaluated and designed on the entire Baranja region. Economic optimisation of this project is to determine the areas where it is economically viable to invest in construction of the network. This is conducted with the MAFIOSI software developed in RUHRGAS Company. The evaluation is based on the following assumptions and data:

- consumption: in the first 5 years 30 % of the consumers fulfils majority of their thermal energy needs from the gas network; in 20 years full potential is reached – 60 % of the consumers fulfils majority of their thermal energy needs from the gas network,
- gas selling price: 0,23 €/m³ for households, 0,18 €/m³ for services, 0,15 €/m³ for industry and agriculture; gas buying price: 0,13 €/m³.

The results of the gas distribution network economic evaluation, shown in the Table 1 and Figure 6, are connected with different colours. The most profitable areas are larger settlements Beli Manastir, Darda and Mece. Further development of the network is starts from those initial areas. As the required internal rate of return lowers, the area of the economically viable gas distribution network becomes larger. Finally, with the minimally required IRR=8 %, it is profitable to build gas distribution network in the entire Baranja region.

Table 1 – Results of the gas distribution network economic evaluation

<table>
<thead>
<tr>
<th>ECONOMIC CONDITION</th>
<th>INVESTMENT (€)</th>
<th>FINAL CONSUMPTION (m³)</th>
<th>FINAL IRR (%)</th>
<th>TIME OF RETURN (YEAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAXIMAL PROFIT</td>
<td>2 200 431</td>
<td>11 696 890</td>
<td>15.78</td>
<td>9</td>
</tr>
<tr>
<td>IRR 14%</td>
<td>3 498 295</td>
<td>14 984 348</td>
<td>13.97</td>
<td>10</td>
</tr>
<tr>
<td>IRR 12%</td>
<td>5 797 453</td>
<td>18 989 098</td>
<td>11.43</td>
<td>11</td>
</tr>
<tr>
<td>IRR 10%</td>
<td>8 401 176</td>
<td>22 850 229</td>
<td>9.74</td>
<td>12</td>
</tr>
<tr>
<td>WHOLE SYSTEM</td>
<td>11 375 654</td>
<td>25 628 170</td>
<td>7.97</td>
<td>14</td>
</tr>
</tbody>
</table>

Figure 6 – Results of the gas distribution network economic evaluation
ELECTRICITY DISTRIBUTION NETWORK PLANNING

Electricity distribution network was in the first step analysed and planned independently on the gas distribution network, i.e. on the assumption that there will be no gas distribution network to lower the consumption of the electrical energy in the following 20 years.

The electricity distribution network planning criteria are:

- load of the lines and transformers under normal conditions up to 100% of thermal current,
- admissible voltage drop in 10(20) kV network under normal conditions up to 8%,
- load of the overhead lines and transformers under fault conditions up to 120% of thermal current,
- admissible voltage drop in 10(20) kV network under fault conditions up to 12%,
- “N-1” criteria for the peak load over 1 MVA; outage of a peak load lower than 1 MVA during the fault repairmen is allowed,
- investment in power delivery quality regarding number and duration of outages generally only if it is justified by lower costs of undelivered energy and losses.

Besides objects required by those basic planning criteria, reconstructions of major electricity distribution objects - 110/35 kV and 35/10 kV substations and 35 kV lines - are included in the investment plan. The basic criteria is time of construction or last reconstruction larger than 40 years. Other less important objects, like 10 kV lines and 10/0.4 kV substations, are assumed to be gradually reconstructed through yearly maintenance.

The results of initial electricity distribution network planning, under the assumption that there will be no gas distribution network on the Baranja region, are shown on the Figure 7 and in the SCENARIO I column in the Table 2. Numbers on the figure correspond to the first column in the table, allowing the overview of all necessary investments in 20 years period.

The next step, which takes into account lowering (or slower rise) of the electrical energy consumption, is shown in the Table 2 under SCENARIOS II – VI, corresponding to different coverage of the Baranja region by gas distribution network, according to results in the Table 1 and Figure 6. For easier overview the results are written in corresponding colours.

Naturally, reconstructions of old 35 kV lines and 110/35 kV and 35/10 kV substations are necessary in all the scenarios, regardless of the load, i.e. existence of the gas distribution network.

Figure 7 – Development of the electricity distribution network
Table 2 – Investments in the Baranja electricity distribution network in 20 years period for different electricity (and gas) consumption scenarios

<table>
<thead>
<tr>
<th>NUMBER</th>
<th>DESCRIPTION OF WORKS</th>
<th>TOTAL COSTS (€)</th>
<th>YEAR OF INVESTMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Construction of new 10 kV feeder from 35/10 kV substation Valpovo (Slavonija region)</td>
<td>142 000</td>
<td>I I I I I I</td>
</tr>
<tr>
<td>2</td>
<td>Construction of new 10 kV line Al/Fe 3×95 mm² in the corridor of the existing 10 kV feeder Kozarac up to 10/0,4 kV substation Karanac</td>
<td>172 000</td>
<td>I I I I I I</td>
</tr>
<tr>
<td>3</td>
<td>Replacement of 4 MVA rated power transformer with 8 MVA in TS 35/10 kV substation Bilje 4+8 MVA</td>
<td>26 000</td>
<td>I I I I I I</td>
</tr>
<tr>
<td>4</td>
<td>Replacement of conductors and insulators along main line of 10 kV feeder Kozarac</td>
<td>56 000</td>
<td>7 7 7 9 - -</td>
</tr>
<tr>
<td>5</td>
<td>Replacement of conductors and insulators along main line of 10 kV feeder Bolman</td>
<td>55 000</td>
<td>7 7 7 7 - -</td>
</tr>
<tr>
<td>6</td>
<td>Replacement of 150 m 10 kV overhead line (type Al/Fe 3×50 mm²) along 10 kV cable feeder Beli Manastir Jug</td>
<td>6 000</td>
<td>7 - - - - -</td>
</tr>
<tr>
<td>7</td>
<td>Replacement of low cross sectioned 10 kV cables along 10 kV cable feeder Beli Manastir Jug</td>
<td>19 000</td>
<td>7 - - - - -</td>
</tr>
<tr>
<td>8</td>
<td>Construction of new 110/10(20) kV substation Darda 1×20 MVA (the 110 kV line Osijek – Beli Manastir passes above the site)</td>
<td>1 848 000</td>
<td>11 - - - - -</td>
</tr>
<tr>
<td>9</td>
<td>Reconstruction of 35 kV overhead line Beli Manastir - Kneževi Vinogradi</td>
<td>261 000</td>
<td>2012</td>
</tr>
<tr>
<td>10</td>
<td>Construction of new 10 kV line Al/Fe 3×95 mm² in the corridor of the existing 10 kV feeder Podunavlje</td>
<td>62 000</td>
<td>13 13 - - - -</td>
</tr>
<tr>
<td>11</td>
<td>Reconstruction of 35 kV plant in 35/10 kV substation Kneževi Vinogradi</td>
<td>195 000</td>
<td>2014</td>
</tr>
<tr>
<td>12</td>
<td>Reconstruction of 35 kV plant in 35/10 kV substation Branjin Vrh</td>
<td>159 000</td>
<td>2016</td>
</tr>
<tr>
<td>13</td>
<td>Reconstruction of 35/10 kV substation Draž</td>
<td>485 000</td>
<td>2016</td>
</tr>
<tr>
<td>14</td>
<td>Reconstruction of 35 kV overhead line Kneževi Vinogradi - Draž</td>
<td>338 000</td>
<td>2016</td>
</tr>
<tr>
<td>15</td>
<td>Reconstruction of 35 kV plant in 110/35/10 kV substation Beli Manastir</td>
<td>695 000</td>
<td>2018</td>
</tr>
<tr>
<td>16</td>
<td>Replacement of 10 kV lines along 10 kV feeders Silos and IMV and connection of those two feeders</td>
<td>183 000</td>
<td>19 - - - - -</td>
</tr>
</tbody>
</table>

TOTAL INVESTMENT IN 20 YEARS (€) | 4 702 000 | 4 702 000 | 2 646 000 | 2 584 000 | 2 584 000 | 2 473 000 | 2 473 000 |
CONCLUSION

Investments in the gas distribution network in Baranja region varies from 2 200 000 € for the network only in three larger settlements to 11 400 000 € for the network on in all settlements, depending on required profitability of the project.
Corresponding investments in electricity distribution network varies from 4 700 000 € in the case without gas distribution network at all to 2 500 000 € in the case of the entire Baranja region covered by the gas distribution network – 47 % lower investment.
The major saving, comprising 92 % of all savings, is achieved with even the smallest investment in the gas distribution network, because of avoiding the construction of expensive 110/10 kV substation Darda. In fact, savings in the electricity distribution network investments because of the initial gas distribution network construction in towns of Beli Manastir, Darda and Mece almost cover the investment costs of those gas distribution networks.