electricity can be held together, but also because fuel savings can be achieved and therefore more an efficient overall conversion process is possible.

Çakir et al. [9] estimate that fuel savings via a cogeneration regime can reach 50 %. Since CHP plants and biofuel production require the same feedstock, Leduc et al. [10] investigated whether the use of biomass should be supported in the EU. The results showed that the CHP plants are preferred over biofuel production plants in cases when carbon costs more than 50 EUR per tCO2 and the support for biofuel is below 10 EUR per GJ. Moreover, the highest potential for both biofuel and CHP was found in the countries around the Baltic Sea, Austria, Czech Republic, Hungary and Poland. The sustainable development of biomass CHP plants in Latvia was studied by Cimdina et al. [11].

Nevertheless the installation of CHP and the conversion of energy production units to renewables are not enough. In sustainable energy production systems, the analysis of operational performance is vital. The literature review traces a wide range of factors affecting the performance of the cogeneration power plant. Cimdina et al. [12] determines the essential factors of the operation performance in biomass cogeneration power by presenting quantitative equations.

Biomass CHP can be assessed using various indicators such as efficiency [13], primary energy savings [14], emergy efficiency [10], internal rate of return (IRR) and net present value (NPV) [15], as well as the costs of heat and power production [16]. Nevertheless, traditionally applied assessment methods of energy and mass flows and economic analysis do not provide an integral assessment. In this case another methodology should be applied. Emergy and exergy analysis could serve as such an integral assessment method [17].

Exergy is defined as the maximal useful work obtained from a system while the system interacts with environment. Nowadays energy and exergy analyses are done for power plants [18] and for various energy technologies, such as internal combustion engines [19], steam turbines [20], [21], gas turbines [22], as well as for district heating systems [23] and technological processes [24]. The objective of each analysis is to investigate possibilities to make a system more efficient and therefore more environmentally-friendly and economically feasible. Exergetic aspects of various legislation is analyzed and compared in Ertesvag [25]. Karklina et al. [26] presents exergy analysis of a cogeneration plant, which shows the vital points of exergy destruction and might be used for the improvement of operations.

Emergy is defined as the available solar energy that has previously been directly or indirectly used to make a product or provide a service [27]. When compared to energy analysis, emergy analysis is more versatile and has wider boundaries. It addresses not only energy and material flows, but also information, services, finance, labor, as well as changes to the environment caused by the production process. Emergy analysis is a way to describe a company in the long run and to assess its sustainability [28]. The application of emergy analysis for electricity production systems were demonstrated by Brown and Ulgiati [29]. The methodology for the application of emergy analysis to study a biomass cogeneration power plant is developed by Cimdina et al. [30]. The methodology is approbated on the case study.

To achieve the policy target, an important role is played by biomass, the energy-efficient use of which is possible due to longstanding traditions in technological development and in economically justified biofuel expenses. However, under electricity market liberalization, the price for electricity is time-variable and creates an economically favorable offer for the plant, if the plant is able to operate dynamically with the variable generation of electrical energy [31]. Therefore Cimdina et al. [32] analyzed the operation conditions for biomass cogeneration plant under dynamic market condition.

The transition from local, separate high efficiency and sustainable energy supply solution to the community based level supply solutions can have various underlying challenges. Firstly, a choice between the various sizes and capacity of cogeneration (CHP) should be made. Secondly, one must choose among different investment priorities; should the investment in energy efficiency be made at the power plant, distribution grid or energy end consumers. Also the integration of biomass CHP for district heating (DH) system is subject to analysis.

Various researchers have addressed the problem about the correct sizing and capacity of CHP within the DH system. Lončar and Ridjan [33] proved that biomass CHP plants in DH give larger primary energy savings than small scale CHP for individual heating and gas-fired CHP for DH. Finney et al. [34] looked at two cities, each at a different stage of networking, centralization and energy system development. The results show that in both cases a wood chip boiler was the more suitable option from the climate change point of view. Studies by Ziębik and Gładysz [35] and Gładysz and Ziębik [36] show the highest influence of the demand for domestic hot water on the optimal share of CHP (with and without thermal storage) in DH networks. The sizing algorithm of biomass-fired Organic Rankine Cycle (ORC) CHP with heat storage has been developed by Taljan et al. [16]. Noussan et al. [15] analysed biomass-fired ORC unit coupled with heat storage system (HSS) in an existing DH system and obtained the highest system's efficiencies at the HSS size of 150 m^3 per MW. Prato et al. [13] proposed another solution for the CHP system with heat storage. In his proposal, the capacity of the DH network was used as dynamic heat storage and this solution was recognized as feasible. Two radically contradictory solutions when choosing the installed capacity of CHP are studied by Cimdina et al. [37]: 1) compliance with the base load of the DH system; and 2) compliance with the optimal heat load of the DH system during the whole year.

Moreover the effective use of energy sources in production units is tightly related to final energy consumption. Since energy efficiency measures lead to reduction of energy demand, the production units (especially in the case of district heating) need to be reorganized by considering relocated load distribution and integration of renewable energy sources. The research by Fahlen and Ahlgren [38] and Fahlen et al. [39] showed that the integration of biomass gasification or absorption cooling in DH system (in the case of load reduction) presents both advantages and shortages. The optimal solutions, in case when heat load in district heating system decreases, is studied by Blumberga et al. [40].

From the short-term point of view, an increase in the share of biomass in DH systems would economically be one of the most optimal paths in changing the country's energy balance in favor of renewable energy sources (RES). However, in the longer run, the integration of intermittent renewable energy technologies on a large-scale should be considered. Nevertheless this solution requires flexible consumers which are able to adapt their consumption to the supply from those sources. DH systems to a certain extent are able to serve a flexible consumer and to participate in the solution of any mismatch between supply and demand from RES. Thus the study by Bazbauers and Cimdina [41] determines to what extent a DH system can serve as a flexible user in the Latvian energy system.

When using biomass for energy production, the question of resource sustainability is usually on the list of things to consider. In Latvia forests cover around 50 % of the territory. While the total growing stock accounts for 631 million m^3 [42], the average forest processing rate is 12 million m^3 per year [43]. The research by Dubrovskis [44] concludes that available biomass potential in Latvia is around 25–30 TWh per year and the annual logging rate complies with the basic principles of sustainable development. Moreover the price of biomass in Latvia is around two times lower than the price of natural gas. Despite these facts, Latvia is not currently among the countries with the highest biomass share in its energy balance.

This fact leads to the conclusion, that the operators of the heat production units and DH networks by themselves cannot lead the sector for sustainable solutions quickly enough. Municipal-level support is critical at the initial phases of development. Research by Madlener

[45] also concludes that sufficient reserves of wood resources are not enough for development of biomass-based DH systems; policy support and grants are also necessary to decrease the share of fossil fuel. Perednis [46] emphasizes that the logistics (collection, storage and transportation) of the biomass should also be solved by promotion schemes and government support to make transition to biomass use more rapid and smooth. Ziemele et al. [47] analyses the use of wood fuel for district heating in Riga's municipality. The study forecasts the share of wood fuel in the thermal energy balance of the municipality. The hypothesis of the research is that 25 % of the total heat energy consumption of Riga's municipality can be supplied using biomass by 2020.

In recent years, new capacity building in increasing dominated by renewable energy technologies. Currently Sweden and Denmark are aiming for 100 % renewable energy sources in their energy strategies by 2050 [48], [49]. Latvia is slowly following the experience of the Nordic countries. Nevertheless, most of the boiler houses and co-generation plants in Latvia are still dependent on natural gas resources [43].

Numerous authors have focused on the estimation of biomass potential at different levels. Voivontas et al. [50] developed a GIS-based method to estimate the economically feasible potential for power production from agricultural residues. Van Dam et al. [51] developed a methodology for the assessment of biomass potential in Central and Eastern European countries. Simon and Wiegman [52] presented the model for analyzing the sustainability potential of agricultural biomass for energy production in Germany, Poland, the Czech Republic and Hungary. Authors concluded that different environmental goals, e.g. climate protection and nature conservation, can come into conflict regarding land use and that the land competition can be eased by intensifying the use of residues. On a narrower scale, Havlickova et al. [53] developed an economic model for biomass price calculation in the Czech Republic and concluded that the price of biomass is mainly affected by harvesting and processing costs. Meanwhile De Wit and Faai [54] and Havlickova et al. [55] concluded that large variations exist in biomass production potential and costs among the European regions. Authors outlined large parts of Poland, the Baltic States (Latvia, Lithuania and Estonia), Romania, Bulgaria and Ukraine as high biomass potential regions. Barisa et al. [55] developed Latvia's national path for the transition to a low carbon strategy, where the potential for various resources is stated. This strategy is presented from technical, environmental and economic points of view.

Transition from a fossil fuel economy to a renewable energy economy is a complex process and requires a long-term development strategy and serious approach to its implementation. Therefore the study by Cimdina et al. [56] analyses strategies for restricting Latvia's dependence on fossil fuel imports in line with an increasing challenge to follow the leading EU Member States in greening the energy sector.

Common targets in low carbon strategies are; to decarbonize the power sector firstly due to its GHG reduction potential; to give the role of the main energy source to biomass; to reduce energy consumption in buildings; to use RES together with smart energy storage, and; to implement cost effective solutions for energy efficiency and RES. Various research was carried out to study the transition to 100 % renewable energy systems at country level for Denmark by Lund and Mathiesen [57] and, Germany by Henning and Palzer [58], Macedonia by Ćosić et al. [59], Protugal by Krajačić et al. [60] and Ireland by Connolly et al. [61], at municipality level for Danish cities Aalborg by Østergaard et al. [62] and Fredrikshavn by Østergaard and Lund [63] and at the European level by Steinke et al. [64], Spiecker and Weber [65] and Rasmussen et al. [66]. Although case studies do not provide a common methodology, they outline a vision of future energy systems, where reduction in fossil fuel consumption is possible. Therefore the study by Blumberga et al. [67] presents methodology underpinning the development of the Green energy strategy 2050 for Latvia.

Based on the literature analysis carried out it can be concluded, that, in order to aim for a low carbon society, the underlining elements of the system – municipality, district heating network and energy production units – should be functioning to reach the same targets. Therefore this work presents the scaling-up framework for state energy sector. Due to authors knowledge this is the first paper presenting this framework for a case study on the energy sector. The focus of this particular work is to present various methodologies suitable for use in various domains of a scaling-up framework.

This presented framework can primarily be applied for energy systems and energy sectors, but its use is not limited and can be applied to other fields of economy as well. Moreover the presented framework can be used both for scientific research purposes and by policy makers.

2. METHODOLOGY

To have a well-functioning and sustainable state energy sector, each of the underlining elements should also function with the maximal efficiency and each in a given moment in time. To ensure maximum efficiency and study possible improvement, the scaling-up framework is presented in this research, see Fig. 1.

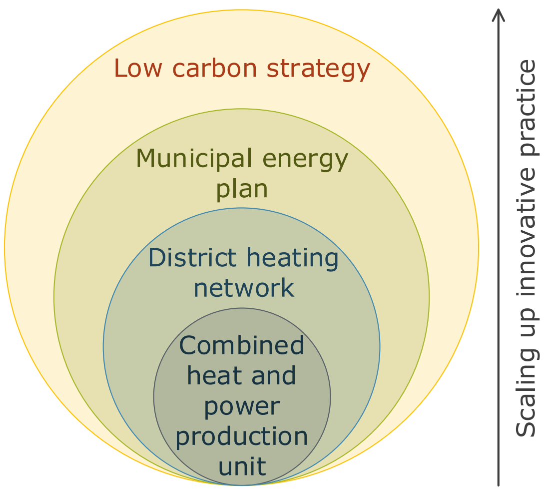

Fig. 1. Scaling-up innovative practices in energy sector using four elements in state energy sector: combined heat and power production unit, district heating network, municipal energy plan and low carbon strategy.

The scaling-up framework means that the starting point is combined heat and power production unit and their operation, next step of aggregation is district heating network, followed by municipal energy plan and finally leading to low carbon strategy.

In this proposed framework, the authors argue, that the successful, innovative practices developed and tested on the lower level of aggregation can be then transferred to the upper levels of aggregation, thus leading to scaling-up effect of innovative practices.

Each of the methodologies presented in this paper were applied for separate sectors, nevertheless some of the methodologies can also be used for other levels of the system.

3. RESULTS AND DISCUSSION

In this section the methodologies used in each of the levels of the system are given, thus providing insight on how the innovative practices can be transferred by scaling-up framework.

3.1. Combined Heat and Power Production Unit as Study Domain

In this section, firstly, the methodology for obtaining various indicatives values of CHP power plant are given, followed by the statistical analysis model – correlation and regression analysis for CHP plant.

3.1.1. Energy analysis

Energy analysis is a widely used method of energy conversion efficiency assessment. The main equations in the energy analysis compare the boiler's energy input with the heat output from the boiler. In addition, the mass of the steam input to the heat exchangers, amount of extracted steam from, useful work of the turbine and the coefficient of performance of steam turbine along with other are obtained during this analysis, see the authors' article [11], [26] for more details.

The main purpose of this analysis is the energy balance in the CHP plant, thus obtaining information about the efficiency and losses for various parts of the plant and various operation modes. This information can be further used to identify no-optimal working conditions and make improvements.

3.1.2. Exergy analysis

Exergy analysis shows points of exergy degradation in a system and allows making a quantitative assessment of energy quality changes. Exergy can be an acceptable tool for measuring the quality of natural resources and can be used to improve sustainability of energy production.

The main equations in the exergy analysis compare exergy at the system's input and output, thus allowing the assessment of exergy degradation along the process. Main analyses flows are exergy input in steam turbine, steam exergy after the turbine, exergy destruction in the steam turbine, input fuel exergy, as well as exergy destruction in boiler, exergy efficiency of the plant and others, see the authors' article [11, 26] for more details.

Exergy analysis is a useful tool for evaluating energy-related systems, showing the quality of energy and its abilities of application wider than in case of energy assessment. Therefore the main purpose of exergy analysis is to identify the "bottle-necks" in the CHP plant and to perform possible improvements to reduce the degradation of exergy.

3.1.3. Emergy analysis

Emergy is the availability of the energy (exergy) of one kind that is used up in transformations directly and indirectly to make a product or service. Studying systems emergy analysis includes all inputs that effects system, economic and environmental aspects are included. Emergy analysis uses transformities to convert all inputs into solar emergy. Transformity is a coefficient which shows how much solar energy is used to create one unit of specific input, see the authors' article [11, 30] for more details.

After calculating systems' emergy, emergy indicators are used for analyzing and describing the system. Several emergy indicators can be used, but one of them describes sustainability of system and it is called environmental sustainability index, *ESI*, see Eq. (1).

$$ESI = EYR / ELR \quad (1)$$

Where the emergy sustainability index is a ratio between the emergy yield ratio, *EYR,* and the environmental loading ratio, *ELR*; see Eq. (2) and Eq. (3) correspondingly.

$$EYR = Y / F = (F + R + N) / F \quad (2)$$

$$ELR = (F + N) / R \quad (3)$$

where

R the share of local renewable resources;

N the share of non-renewable resources;

F the external investment per unit.

As a relative measure, if ESI is less than 1, the system is not sustainable. Medium sustainability is at the measure 1–5 and when systems' EIS is greater than 5, the system can be called sustainable [29].

The emergy analysis is still in the development phase therefore data availability for various flow can be limitation and uncertainty cause. Nevertheless in the terms of composite indicator application for evaluation of the systems performance emergy analysis is competitive tool to use.

3.1.4. Correlation analysis

The linkage between the parameters in CHP is proposed to be studied by means of performing the correlation analysis. Based on the correlation analysis, a regression equation is selected. The correlation analysis is considered to be a tool. The result of the correlation analysis can be further used as a basis of information for other methodologies.

The strength of the mutual link of independent and dependent random variables (correlation) can be assessed by means of a correlation coefficient. In case of a single factor mathematic model, the Pearson's equation is used for its estimations; see the authors' article [12] for more details.

The first application of the correlation analysis is aimed at establishing whether there is a correlation between the dependent variable and the analysed independent variable describing the operation of the CHP plant. In this case, the value of the correlation coefficient is low and there is a dispersion of data, which leads to the conclusion that there is considerable impact from other factors.

The impact of other factors can be established by means of a multi-factor regression analysis. Application of a multi-factor regression analysis is correct if there is no mutual correlation between independent variables. If there is such correlation, the parameters will have to be excluded from the regression equation.

In the result of the proposed correlation analysis, it is obtained that within further multi-factor regression analysis the change of the specific fuel consumption of the CHP plant, b_{ch} (dependent variable) could be described by four independent factors – the boiler efficiency N_b/B, the power generation efficiency N_{el}/B, the heat production efficiency Q_{th}/B and the outdoor temperature, T_{out}; see Eq. (4).

$$b_{ch} = f\left(\frac{N_b}{B}; \frac{N_{el}}{B}; \frac{Q_{th}}{B}; T_{out}\right) \quad (4)$$

Following the establishment of the regression equation, it is possible to perform the rules verification of the correct application of the regression analysis based upon a range of other indices. These are autocorrelation, multicolinearity and heteroscedasticity.

By applying the Durbin-Watson's test, in the course of statistical treatment of the data and the data analysis, the DW criterion has been established. When value exceeds the marginal value of 1.4, this means that there is no considerable autocorrelation of the balance and the assessments of values by means of the smallest squared values method in the course of the analysis are not deformed. The verification of multicolinearity was performed by analysing the correlation matrix of the coefficients calculated by means of the regression equation. Finally, the heteroscedasticity test was performed by means of a graph analysis of the distribution of balances depending on the outdoor temperature.

3.1.5. Regression analysis

The regression analysis defines accurate quantitative parameters of the change in random variables, i.e. explains the importance of the stochastic link by functional relationships.

The regression analysis aims to obtain an empirical equation that would provide a quantitative description of the change in the specific fuel consumption of the CHP plant depending on statistically important operational indices of this plant; and therefore the obtained equation would serve as the basis for forecasting and evaluating the specific fuel consumption of this CHP plant.

The performed data correlation analysis makes regression analysis easier, since the set of factors that needs to be included in the multi-factor regression equation has been established by correlation analysis, see the authors' article [12] for more details.

When empirical models are developed in the form of the regression equation, two questions always need to be solved: 1) whether the model comprises all the independent variables describing the analyzed phenomenon and 2) whether the model does not comprise unnecessary and non-essential variables, thus making the model too complicated.

The regression equation was proposed for CHP plant that contains statistically important independent variables, see Eq. (5).

$$f_{ch} = b_0 + b_1 . \frac{N_b}{B} + b_2 . \frac{N_{el}}{B} + b_3 . \frac{Q_{th}}{B} + b_4 . T_{out} \, , \tag{5}$$

where

N_b/B the boiler efficiency,
N_{el}/B the power generation efficiency,
Q_{th}/B the heat production efficiency,
T_{out} the outdoor temperature.

The evaluation of the adequacy of the regression equation is performed by means of the dispersion analysis by applying Fisher's criterion.

3.2. District Heating Network as Study Domain

In this section, firstly, the methodology for comparing various alternative solutions in a district heating system is given, followed by the model for the alternative operation modes of CHP when the load of this plant diminishes, and finally, the generic model of DH with the integration of renewables is given.

3.2.1. Multiple-criteria decision analysis methodology

The methodology was developed to allow making a comparison of various alternative solutions, where the efficiency of the use of primary energy resources is analyzed. The model of multiple-criteria decision analysis is the main part of this developed methodology. The other eight modules are additional modules in this presented methodology, by means of which data for the multiple-criteria decision analysis module are provided. They include the module of the input data of the DH system, as well as the schedule of the heat load length and calculation modules. However, special focus has been placed on the selection of criteria. The criteria that are used for the multiple-criteria analysis are energy efficiency, operational costs, investment costs, load coefficient; see the authors' article [37] for more details.

The proposed methodology uses the Technique of Order Preference by Similarity (TOPSIS) for analysis. To start TOPSIS analysis, data must be arranged in the form of a decision making matrix and then to normalized and weighted, see equation matrix (6).

$$
\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_n \end{array}
\begin{array}{c} \begin{array}{cccccc} w_1 b_1 & w_2 b_2 & \cdots & w_j b_j & \cdots & w_n b_n \end{array} \\
\begin{bmatrix}
w_1 b_{11}^k & w_2 b_{12}^k & \cdots & w_j b_{1j}^k & \cdots & w_n b_{1n}^k \\
w_1 b_{21}^k & w_2 b_{22}^k & \cdots & w_j b_{2j}^k & \cdots & w_n b_{2n}^k \\
\vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\
w_1 b_{i1}^k & w_2 b_{i2}^k & \cdots & w_j b_{ij}^k & \cdots & w_n b_{im}^k \\
\vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\
w_1 b_{n1}^k & w_2 b_{n2}^k & \cdots & w_j b_{nj}^k & \cdots & w_n b_{nm}^k
\end{bmatrix} \end{array} \tag{6}
$$

Where n evaluation criterions are given as x_j and m alternatives as A_i. Normalized data is weighted by multiplying data with criterion weights w_j.

3.2.2. The model of alternative operational loads

Sustainable development of heat supply system depends on load development, therefore it is needed to analyse a situation when heat consumption is reduced based on energy efficiency measures or because of climate change. Therefore the model for the alternative operation modes of a CHP is presented in the situation when the load of this plant diminishes.

The delay in the realisation of energy efficiency measures determines that the heat consumption is initially reduced rather slowly, until the break point, from where a more intensive period of energy efficiency measures starts. This phenomenon is called the decline by S-shape curve; see the authors' article [40] for more details.

The model assumes that heat load in the future is covered by competing plants, and operation of these plants is established by three technical parameters: power-to-heat ratio of cogeneration plants, α, efficiency, η, and share of renewable energy in the energy balance, k. Three parameters have to be maximised for the whole year period.

The model also considers adaptation of the plants to the new conditions. All alternatives which are chosen are justified from economic, environmental and climate change aspects and correspond to the base requirement, i.e. operation in the cogeneration-mode.

Surplus heat, produced by the cogeneration plant during periods of low demand can be stored in the heat storage system, and the stored heat can be taken from the heat storage to cover required peak loads at periods of the high demand when the capacity of the cogeneration plant is not sufficient.

3.2.3. The generic model of district heating system

Sustainable district heating system means that more renewable resources will be integrated into the network. Nevertheless, such resources as wind and solar energy have intermittent patterns and therefore are subject to underlying optimization questions of the current system.

Modelling of DH systems with the integration of RES technologies, has an intermittent character and therefore the sufficiently small time-step of modelling is needed for accurate predictions. The Energy System Analysis Model "EnergyPLAN" which is developed at Aalborg University in Denmark was chosen as the modelling tool to solve this modelling problem.

Using "EnergyPLAN", the generic model of DH system are developed and analyzed. The aim of this generic model is to study the role of the DH system in advancing more sustainable energy supply systems, in particular integration of wind power plant (WPP); see the authors' article [41] for more details.

The model assumes, that it will take some time before large capacities of WPP can be added to the energy system, and it can be expected that, due to energy efficiency measures, the district heat consumption may decrease, in spite of new heated space construction during this time.

The opposite is expected regarding electricity consumption and, although energy efficiency will also increase in the power sector, electricity demand will most likely go up along with economic expansion.

Moreover, the role of heat storage is shown in the model; it is to accumulate the excess heat produced by heat pumps during surplus WPP production periods, as well as allow using extra CHP capacity to replace condensing power production when such opportunities arise.

3.3. Municipal Energy Plan as Study Domain

In this section, the methodology using time series and climate indicators is presented for application at the level of municipal energy plan.

3.3.1. Time series forecasting

For the model time series forecasting based on the ARIMA (p, d, q) x (P, D, Q) model was chosen. It has been widely used for modelling in different scientific fields and shows advantages over other models. The selected time period was 1 month and the seasonality 12 months. The model was used to forecast the amount of heat energy at the municipality level; see the authors' article [47] for more details.

The general form of the model can be expressed in terms of the backwards operator *B* that operates on the time index of a data value. Using this operator, the model takes the form given in Eq. (7).

$$\begin{aligned}&(1-B-B^2-\ldots B^p)(1-B^s-B^{2s}-\ldots B^{Ps})(1-B)^d(1-B^s)^D(Y_{t-\mu})=\\&=(1-B-B^2-\ldots B^q)(1-B^s-B^{2s}-\ldots B^{Qs})\alpha_t\end{aligned} \tag{7}$$

Where a_t is a random error or shock to the system at time t, and μ represents the process mean for the stationary series.

A residual autocorrelation function with a confidence level of 95 % is proposed to test the forecast model. Where, the residual autocorrelation at lag k measures the strength of the correlation between residuals k time period apart. The residual lag k autocorrelation is calculated based as in Eq. (8).

$$r_k = \frac{\sum_{t=1}^{n-k}(e_t - \bar{e})(e_{t+k} - \bar{e})}{\sum_{i=1}^{n}(e_t - \bar{e})^2} \quad (8)$$

Where t is the time period, e_t is one period ahead of forecasting, n is the sample size (number of observations used to fit the model), $t + k$ is the forecasting time. The developed STATGRAPHICS Centurion forecasting model was compared with the regression model developed from the yearly data.

3.3.2. Climate indicator calculation

The installation of new technologies using renewable energy sources means that fossil fuels are no longer necessary. This reduces the amount of emissions emitted to the atmosphere as a result of a change in fuel and development of advanced combustion technologies with increased boiler efficiency. The indicator of the avoided GHG emissions E (t CO_2 per year) is proposed to be used in this model.

3.4. Low Carbon Strategy as Study Domain

In this section, the methodology using system's archetype "distraction" and four-step management system is presented for the application at the level of low carbon strategy.

3.4.1. System's archetype "distraction"

It is hard to think in the long term when facing a short-term problem – energy consumption increase. There is great temptation to solve this problem using the simplest of solutions – importing more energy. The more attention is paid to short-term solution, the less it is dedicated to the long term – the use of RES.

From the perspective of systemic thinking, this problem has been described by Senge [68] through the archetype "distraction". This archetype reflects the effect of energy sector dependence and short-term planning on the situation in the energy sector in the long-term. The system's archetype is schematically given in Fig. 2.

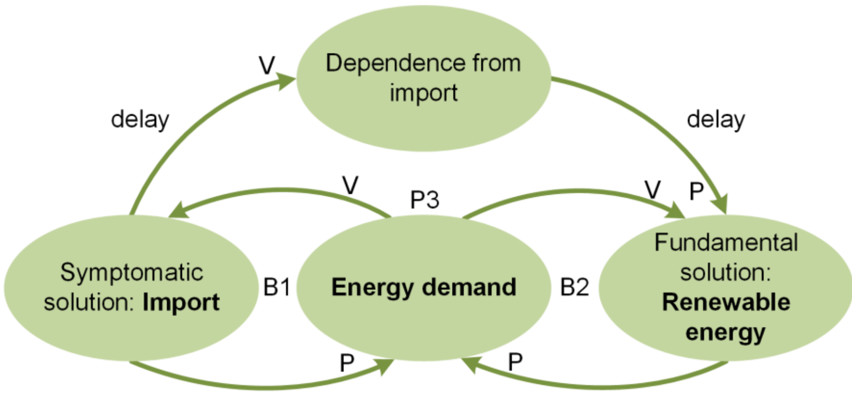

Fig. 2. System's archetype "distraction" (P – contrary processes, V – equal processes, B1, B2 – balancing loops, P3 – balancing loop).

The main idea behind this archetype is that in the case when a symptomatic or short-term solution is used at least once, the implementation of fundamental or long-term solution is postponed; see the authors' article [56] for more details.

The example to show a short-term solution which delays implementation of long-term solution, such as the immediate need to renovate an existing DHS in a municipality which is done immediately without considering addition investments and a switch to RES at the same time would produce better results in the long-term, although might immediately cost the municipality more financial, technical resources.

The best illustration of the circumstance mentioned above is a specific situation with energy production from renewable energy resources in Latvia. Despite the fact that it is already possible to achieve a 70–80 % share of renewable resources in district heating energy supply in this decade, existing regulatory measures and policy instruments hinder this development. Therefore the transition from a fossil fuel economy to a renewable energy economy is a complex process and requires a long-term development strategy and serious approach to its implementation.

3.4.2. Four-step management system

To accomplish the transfer of the national economy from fossil to renewable energy resources, it is necessary to define directions, objectives and principles for such transformation. The algorithm of methodology presents four steps as given in Fig. 3.

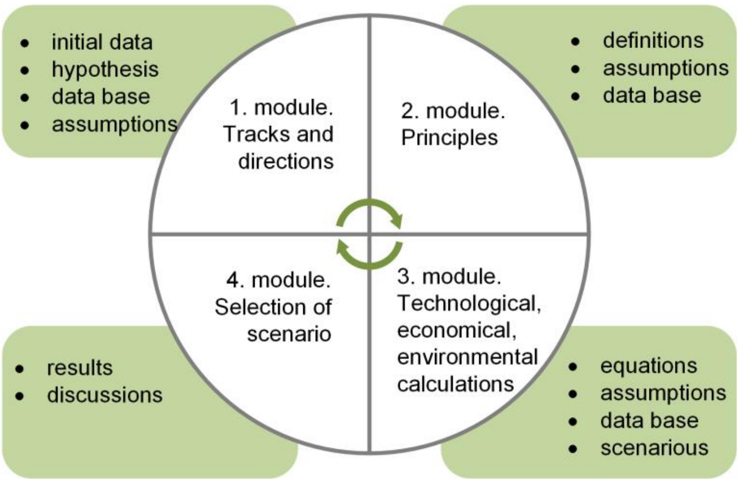

Fig. 3. Algorithm of four-step management approach.

Module 1. Tracks and directions determine how to meet the commitment of the country and which are the priority sectors. Therefore, the strategy must have at least three parallel tracks:

- Track 1: Transition to more energy-efficient energy consumption and use of renewable energy sources:
- Track 2: Integration of new solutions in the energy sector and transport system:
- Track 3: Research, development and demonstration:

Module 2. Principles comprise financial, environmental, climate, socio-economic and management aspects. These principles include cost efficiency of the measures, minimal impact on public funding, renewed competitiveness, flexibility principle, full-bodied use of international cooperation, securing a energy supply system bottom-up model, support to centralized principle in heating supply, flexibility of energy industry system, market model, business model, gradual approach, sustainable development model, level mark model, assessment model, see the authors' article [56] for more details.

Module 3. Calculations should be made taking into account learning and cost curves of the technologies. All of this emphasizes the need for a flexible strategy, which ends with opportunities for technology development. Problems relevant to energy supply safety and impact on climate change can also be resolved in different ways.

Module 4. Selections of scenarios are affected by a variety of factors: distribution among different renewable energy sources, technology parameters, economic indicators, etc. In the period up to 2020, the main emphasis must be on a more complete use of biomass, without neglecting the use of wind energy after 2020 and the use of solar energy primarily in multi-apartment houses, thus ensuring hot water supply.

4. CONCLUSION

To have well-functioning and sustainable state energy sector, each of the underlining elements should also function with maximum efficiency and each within a given moment of the time. To ensure maximum efficiency and study possible improvement, the scaling-up framework is presented in this work. The scaling-up framework is applied for a case study – state energy sector.

The scaling-up framework means that the starting point is a combined heat and power production unit and its operation, the next step of aggregation is district heating network, followed by municipal energy plan and finally leading to a low carbon strategy.

In this proposed framework the authors argues, that the successful, innovative practices, that are developed and tested on the lower level of aggregation can be then transferred to the upper levels of aggregation, thus leading to scaling-up effect of innovative practices.

The focus of this particular work is to present various methodologies suitable for use in various domains of scaling-up framework. This work summarizes 12 various methodologies used in the energy sector, by dividing these methodologies among the various levels of aggregation in the scaling-up framework.

For the combined heat and power production unit as the study domain, firstly, the methodology for obtaining various indicatives values of a CHP power plant are given, followed by the statistical analysis model – correlation and regression analysis fora CHP plant.

For the district heating network as the study domain, firstly, the methodology for comparing various alternative solutions in district heating system is given, followed by the model for the alternative operation modes of CHP when the load of this plant diminishes, and finally, the generic model of DH with the integration of renewables is given.

For the municipal energy plan as the study domain, the methodology using time series and a climate indicator are presented for the application at the level of municipal energy plan.

Finally, for the low carbon strategy as the study domain, the methodology using system's archetype "distraction" and four-step management system is presented for application at the level of a low carbon strategy.

Each of the methodologies presented in this paper is applied for separate sectors nevertheless some of the methodologies can also be used for other levels of the system.

This presented framework can be primarily applied for energy systems and energy sectors, but their use is not limited and can be applied to other fields of economy as well. Moreover the presented framework can also be used for scientific research purposes as by policy makers.

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REFERENCES

[1] Judl J., Koskela S., Korpela T., Karvosenoja N., Häyrinen A., Rantsi J. Net environmental impacts of low-share wood pellet co-combustion in an existing coal-fired CHP (combined heat and power) production in Helsinki, Finland. *Energy* 2014:77:844–851. doi:10.1016/j.energy.2014.09.068
[2] Haberl H., Beringer T., Bhattacharya S. C., Erb K. H., Hoogwijk M. The global technical potential of bio-energy in 2050 considering sustainability constraints. *Current Opinion in Environmental Sustainability* 2010:2(5–6):394–403. doi:10.1016/j.cosust.2010.10.007
[3] EC, European Commission, Energy 2020. A strategy for competitive, sustainable and secure energy, COM (2010) 639 Final, 2010, 21 p.
[4] EC, European Commission, Informative report long-term energy strategy of Latvia 2030 – competitive energy for the society, 2015, 12 p.
[5] EC, European Commission, Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC, Off. J. Eur. Union, 2004, 50–60.
[6] Frangopoulos C. A. A method to determine the power to heat ratio, the cogenerated electricity and the primary energy savings of cogeneration systems after the European Directive. *Energy* 2012:45(1):52–61. doi:10.1016/j.energy.2011.12.044
[7] Srirangan K., Akawi L., Moo-Young M., Chou C. P. Towards sustainable production of clean energy carriers from biomass resources. *Applied Energy* 2012:100:172–186. doi:10.1016/j.apenergy.2012.05.012
[8] Raj N. T., Iniyan S., Goic R. A review of renewable energy based cogeneration technologies. *Renewable and Sustainable Energy Reviews* 2011:15(8):3640–3648. doi:10.1016/j.rser.2011.06.003
[9] Çakir U., Çomakli K., Yüksel F. The role of cogeneration systems in sustainability of energy. *Energy Conversion and Management* 2012:63:196–202. doi:10.1016/j.enconman.2012.01.041
[10] Leduc S., Wetterlund E., Dotzauer E., Kindermann G. CHP or biofuel production in Europe? *Energy Procedia* 2012:20:40–49. doi:10.1016/j.egypro.2012.03.006
[11] Cimdina G., Prodanuks T., Veidenbergs I., Blumberga D. Sustainable Development of Biomass CHP in Latvia, *Energy Procedia* 2015 – Article in Press.
[12] Cimdiņa G., Veidenbergs I., Kamenders A., Ziemele J., Pakere I., Blumberga A., Blumberga D. Modelling of biomass cogeneration plant efficiency. Agronomy Research 2014:12 (2):455–468.
[13] Prato A. P., Strobino F., Broccardo M., Giusino L. P. Integrated management of cogeneration plants and district heating networks. *Applied Energy* 2012:97:590–600. doi:10.1016/j.apenergy.2012.02.038
[14] Sha S., Hurme M. Emergy evaluation of combined heat and power plant processes. *Applied Thermal Engineering* 2012:43:67–74. doi:10.1016/j.applthermaleng.2011.11.063
[15] Noussan M., Abdin G. C., Poggio A., Roberto R. Biomass-fired CHP and heat storage system simulations in existing district heating systems. *Applied Thermal Engineering* 2014:71(2):729–735. doi:10.1016/j.applthermaleng.2013.11.021
[16] Taljan G., Verbič G., Pantoš M., Sakulin M., Fickert L. Optimal sizing of biomass-fired Organic Rankine Cycle CHP system with heat storage. *Renewable Energy* 2012:41:29–38. doi:10.1016/j.renene.2011.09.034
[17] Brown M. T., Ulgiati S. Emergy analysis and environmental accounting. *Encyclopedia of Energy* 2004:2:329–354.
[18] Pal M., Kumar A., Chandra H. Energy and exergy analysis of boiler and turbine of coal fired thermal power plant. *International Journal of Engineering Research & Technology* 2013:2(6):1428–1439.
[19] Yingjian L., Qi Q., Xiangzhu H., Jiezhi L. Energy balance and efficiency analysis for power generation in internal combustion engine sets using biogas. *Sustainable Energy Technologies and Assessments* 2014:6:25–33. doi:10.1016/j.seta.2014.01.003
[20] Holmberg H., Ruohonen P., Ahtila P. Determination of the real loss of power for a condensing and a backpressure turbine by means of second law analysis. *Entropy* 2009:11:702–712. doi:10.3390/e11040702
[21] Kanoglu M., Dincer I. Performance assessment of cogeneration plants. *Energy Conversion and Management* 2009:50:76–81. doi:10.1016/j.enconman.2008.08.029
[22] Ghazikhani M., Khazaee I., Abdekhodaie E. Exergy analysis of gas turbine with air bottoming cycle. *Energy* 2014:72:599–607. doi:10.1016/j.energy.2014.05.085

[23] Kecebas A. Energetic, exergetic, economic and environmental evaluations of geothermal district heating systems: an application. *Energy Conversion and Management* 2013:65:546–556.
[24] Kaska O. Energy and exergy analysis of organic Rankine for power generation from heat recovery in steel industry. *Energy Conversion and Management* 2014:77:108–117. doi:10.1016/j.enconman.2013.09.026
[25] Ertesvag I. Exergetic comparison of efficiency indicators for combined heat and power (CHP). *Energy* 2007:32:2038–2050. doi:10.1016/j.energy.2007.05.005
[26] Karklina K., Cimdina G., Veidenbergs I., Blumberga D. Energy and exergy analysis of wood-based CHP. Case study. *Energy Procedia* 2015 – Article in Press.
[27] Odum H. T. Environmental accounting: emergy and environment decision making, New York: John Wiley and Sons, 1996, 384 p.
[28] Brown M. T., Ulgiati S. Emergy-based indices and ratios to evaluate sustainability: monitoring economies and technology toward environmentally sound innovation. *Ecological Engineering* 1997:9(1–2):51–69.
[29] Brown M. T. Ulgiati S. Emergy evaluations and environmental loading of electricity production systems. *Journal of Cleaner Production* 2002:10:321–334. doi:10.1016/S0959-6526(01)00043-9
[30] Cimdiņa G., Prodaņuks T., Veidenbergs I., Blumberga D. Review-Based Emergy Analysis of Energy Production. Environment. Technology. Resources: Proceedings of the 10th International Scientific and Practical Conference 2015:2:85–90. doi:10.17770/etr2015vol2.629
[31] Mitra S., Sun L., Grossmann I. E. Optimal scheduling of industrial combined heat and power plants under time-sensitive electricity prices. *Energy* 2013:54:194–211. doi:10.1016/j.energy.2013.02.030
[32] Cimdina G., Blumberga D., Veidenbergs I. Analysis of Wood Fuel CHP Operational Experience. Energy Procedia 2015:72:263–269. doi:10.1016/j.egypro.2015.06.038
[33] Lončar D., Ridjan I. Medium term development prospects of cogeneration district heating systems in transition country – Croatian case. *Energy* 2012:48(1):32–39. doi:10.1016/j.energy.2012.07.025
[34] Finney K. N., Zhou J., Chen Q., Zhang X., Chan C., Sharifi C. N., Swithenbank J., Nolan A., White S., Ogden S., Bradford R. Modelling and mapping sustainable heating for cities. *Applied Thermal Engineering* 2013:53(2):246–255. doi:10.1016/j.applthermaleng.2012.04.009
[35] Ziębik A., Gładysz P. Optimal coefficient of the share of cogeneration in district heating systems. *Energy* 2012:45:220–227. doi:10.1016/j.energy.2012.02.071
[36] Gładysz P., Ziębik A. Complex analysis of the optimal coefficient of the share of cogeneration in district heating systems. *Energy* 2013:62:12–22. doi:10.1016/j.energy.2013.04.032
[37] Cimdina G., Slisane Dz., Ziemele J., Vitolins V., Vigants G., Blumberga D. Sustainable Development of Renewable Energy Resources. Biomass Cogeneration Plant. Proceedings of the 9th International Conference „Environmental Engineering" 2014:256:1–7. doi:10.3846/enviro.2014.256
[38] Fahlen E., Ahlgren E. O. Assessment of integration of different biomass gasification alternatives in a district heating system. *Energy* 2009:34:2184–2195. doi:10.1016/j.energy.2008.10.018
[39] Fahlen E., Trigg L., Ahlgren E. O. Assessment of absorption cooling as a district heating system strategy – A case study. *Energy Conversion and Management* 2012:60:115–124.
[40] Blumberga D., Bazbauers G., Blumberga A., Cimdina G., Rochas C. Development of district heating systems – cogeneration versus energy efficiency of end user. Proceedings of the 13th International Symposium on District Heating and Cooling 2012:17–24.
[41] Bažbauers G., Cimdiņa G. The Role of the Latvian District Heating System in the Development of Sustainable Energy Supply. Environmental and Climate Technologies 2011:7:27–31. doi:10.2478/v10145-011-0024-0
[42] CSB, Latvian Central Statistical Bureau database, available at: www.csb.gov.lv, 2013.
[43] Barisa A., Cimdina G., Romagnoli F., Blumberga D. Potential for bioenergy development in Latvia: Future trend analysis. *Agronomy Research* 2013:11(2):275–282.
[44] Dubrovskis D. Forest resource in Latvia. Materials of the 5th Latvian Green Energy Forum, 7th September, Riga, Latvia.
[45] Madlener R. Innovation diffusion, public policy, and local initiative: The case of wood-fuelled district heating systems in Austria. *Energy Policy* 2007:35(3):1992–2008. doi:10.1016/j.enpol.2006.06.010
[46] Perednis E., Katinas V., Markevičius A. Assessment of wood fuel use for energy generation in Lithuania. *Renewable and Sustainable Energy Reviews* 2012:16(7):5391–5398. doi:10.1016/j.rser.2012.05.044
[47] Ziemele J., Pakere I., Talcis N., Cimdiņa G., Vīgants Ģ., Veidenbergs I., Blumberga D. Analysis of wood fuel use development in Riga. *Agronomy Research* 2014:12(2):645–654.
[48] Joelsson J., Gustavsson L. Swedish biomass strategies to reduce CO_2 emission and oil use in an EU context. *Energy* 2012:43:448–468. doi:10.1016/j.energy.2012.03.050
[49] Parajuli R. Looking into the Danish energy system: Lesson to be learned by other communities. *Renewable and Sustainable Energy Reviews* 2012:16:2191–2199. doi:10.1016/j.rser.2012.01.045
[50] Voivontas D., Assimacopoulos D., Koukios E. G. Assessment of biomass potential for power production: a GIS based method. *Biomass and Bioenergy* 2001:20:101–112. doi:10.1016/S0961-9534(00)00070-2
[51] Van Dam J., Faaij A. P. C, Lewandowski I., Fischer G. Biomass production potentials in Central and Eastern Europe under different scenarios. *Biomass and Bioenergy* 2007:31:345–366. doi:10.1016/j.biombioe.2006.10.001

[52] Simon S. Wiegman K. Modelling sustainable bioenergy potentials from agriculture for Germany and Eastern European countries. *Biomass and Bioenergy* 2009:33:603–609. doi:10.1016/j.biombioe.2008.10.001
[53] Havlickova K., Weger J., Knapek J. Modelling of biomass prices for bio-energy market in the Czech Republic. *Simulation Modelling Practice and Theory* 2011:19:1946–1956. doi:10.1016/j.simpat.2011.04.002
[54] De Wit M., Faai A. European biomass resource potential and costs. *Biomass and Bioenergy* 2010:34:188–202. doi:10.1016/j.biombioe.2009.07.011
[55] Barisa A., Cimdina G., Romagnoli F., Blumberga D. Potential for bioenergy development in Latvia: future trend analysis. *Agronomy Research* 2013:11(2):275–282.
[56] Cimdiņa G., Blumberga A., Veidenbergs I., Blumberga D., Barisa A. The Natural Gas Addiction and Wood Energy Role in Latvia Today and Future. Proceedings of the 2013 International Conference on Mechanics, Fluids, Heat, Elasticity and Electromagnetic Fields (MFHEEF 2013), 2013:147–152.
[57] Lund H., Mathiesen B. V. Energy system analysis of 100 % renewable energy systems – The case of Denmark in years 2030 and 2050. *Energy* 2009:34:524–531. doi:10.1016/j.energy.2008.04.003
[58] Henning H. M., Palzer A. A comprehensive model for the German electricity and heat sector in a future energy system with a dominant contribution from renewable energy Technologies — Part I: Methodology. *Renewable and Sustainable Energy Reviews* 2014:30:1019–1034. doi:10.1016/j.rser.2013.09.012
[59] Ćosić B., Krajačić G., Duić N. A 100 % renewable energy system in the year 2050: The case of Macedonia. *Energy* 2012:48:80–87. doi:10.1016/j.energy.2012.06.078
[60] Krajačić G., Duić N., Zmijarević Z., Mathiesen B. V, Vučinić A. A, da Graça Carvalho M. Planning for a 100 % independent energy system based on smart energy storage for integration of renewables and CO_2 emissions reduction. *Applied Thermal Engineering* 2011:31:2073–2083. doi:10.1016/j.applthermaleng.2011.03.014
[61] Connolly D., Lund H., Mathiesen B. V., Leahy M. The first step towards a 100 % renewable energy-system for Ireland. *Applied Energy* 2011:88:502–507. doi:10.1016/j.apenergy.2010.03.006
[62] Østergaard P. A., Mathiesen B. V., Möllera B., Lund H. A renewable energy scenario for Aalborg Municipality based on low-temperature geothermal heat, wind power and biomass. *Energy* 2010:35:4892–4901. doi:10.1016/j.energy.2010.08.041
[63] Østergaard P. A., Lund H. A renewable energy system in Frederikshavn using low-temperature geothermal energy for district heating. *Applied Energy* 2011:88:479–487. doi:10.1016/j.apenergy.2010.03.018
[64] Steinke F., Wolfrum P., Hoffmann C. Grid vs. storage in a 100 % renewable Europe. *Renewable Energy* 2013:50: 826–832. doi:10.1016/j.renene.2012.07.044
[65] Spiecker S., Weber Ch. The future of the European electricity system and the impact of fluctuating renewable energy – A scenario analysis. *Energy Policy* 2014:65:185–197. doi:10.1016/j.enpol.2013.10.032
[66] Rasmussen M. G., Andresen G. B., Greiner M. Storage and balancing synergies in a fully or highly renewable pan-European power system. *Energy Policy* 2012:51:642–651. doi:10.1016/j.enpol.2012.09.009
[67] Blumberga D., Cimdiņa G., Timma L., Blumberga A., Rošā M. Green energy strategy 2050 for Latvia: a pathway towards a low carbon society. Chemical Engineering Transactions 2014:39:1507–1512. doi:10.3303/CET1439252
[68] Senge P. The Fifth Discipline. The Art and Practice of the Learning Organization, 1990.

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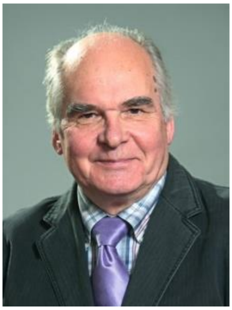

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