TALLINN UNIVERSITY OF TECHNOLOGY
DOCTORAL THESIS
33/2018

Research and Development of Improved Value Stream Mapping Methodology for Evaluation of Demand Side Management Possibilities in the Industry Sector

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TTÜ PRESS

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This dissertation was accepted for the defence of the degree 16/04/2018

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Defence of the thesis: 20/06/2018, Tallinn

Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology, has not been previously submitted for doctoral or equivalent academic degree.

Raivo Melsas

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ISSN 2585-6898 (publication)
ISBN 978-9949-83-236-1 (publication)
ISSN 2585-6901 (PDF)
ISBN 978-9949-83-237-8 (PDF)

TALLINNA TEHNIKAÜLIKOOL
DOKTORITÖÖ
33/2018

Väärtusahela kaardistamise metoodika uurimine ja arendamine tarbimise juhtimise võimaluste hindamiseks tööstussektoris

RAIVO MELSAS

TTÜ KIRJASTUS

Contents

List of Publications

The list of author’s publications, on the basis of which the thesis has been prepared:

I R. Melsas, A. Rosin and I. Drovtar, "Wind park cost efficiency increase through direct cooperation with demand side response provider," 2016 57th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Riga, 2016, pp. 1-5. doi: 10.1109/RTUCON.2016.7763119

II R. Melsas, A. Rosin and I. Drovtar, "Value stream mapping for evaluation of load scheduling possibilities in a district heating plant," 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), Florence, 2016, pp. 1-6. doi: 10.1109/EEEIC.2016.7555696

III Melsas, R.; Rosin, A.; Drovtar, I. (2016). “Value Stream Mapping for Evaluation of Load Scheduling Possibilities in a District Heating Plant.” Transactions on Environment and Electrical Engineering, 1 (3), 62−67.10.22149/teee.v1i3.34.

IV R. Melsas and A. Rosin, "Use of value stream mapping for evaluation of load conservation and peak clipping possibilities," 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Milan, 2017, pp. 1-6. doi: 10.1109/EEEIC.2017.7977549

Author's Contribution to the Publications

Contribution to the papers in this thesis are:

I Raivo Melsas was the main author. He wrote the paper and was responsible for the literature overview, data collection, calculations and analysis. He made the presentation of the paper at the 2016 57th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON) in Riga.

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1 Introduction

1.1 Motivation and background

Development of energy systems has reached the state where the output of the production units is increasingly unpredictable and is to a great degree dependent on the weather. Photovoltaic cells and wind turbines have been commercially used in energy systems more than for four decades and their share in energy systems has acquired a remarkable portion in different countries. Renewable energy production units with unpredictable output are growing faster than any other energy source and their falling costs support the growth heavily. In many countries, far-fetched strategies support power production growth; for instance, in the EU, the target is to reach 20% in 2020. To reach the target requires huge amounts of investments and support. Fig.1 shows the development of renewable energy production in the European Union (EU) countries and the target for 2020. [1].

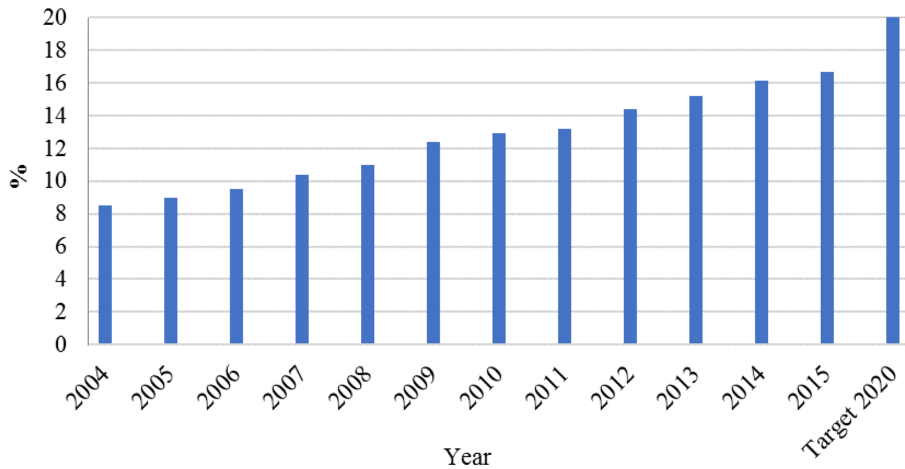

Fig. 1 Share of renewable energy production in EU (28 countries).

Deployment of a large share of renewable energy from unpredictable energy sources such as wind and solar result in a decreasing electricity price. This is due to two facts. First, public subsidy systems cannot react fast when technologies become cheaper. As a result, supported power production can be profitable even at low electricity price. Second, the source of primary energy is free of charge for less predictable solar and wind power production units. Renewable energy has negligible or almost zero marginal running costs. This can result in energy system instability where power production units on fossil fuels with significant primary energy price have to compete in the market and also provide system stability.

The problem cannot be solved by having less power from renewable energy, but rather by more sophisticated control of the energy systems. Development of automation technology smart meters and batteries creates solutions for better control of the consumption loads in energy systems. This helps to cope with intermittent supply systems. Also, the task is to cope with the change on regulatory side. Market regulations have to support flexible supply and demand. Market should reward consumers to use less power to balance the grid, just as they reward production units to generate more by capacity payments. Demand side management (DSM) in production facilities can play an important role as active participants in the future energy markets, helping to keep energy systems in a stable state through DSM.

DSM is a key role player in energy savings as well, as it contains not only consumer dynamic actions like demand response but also energy efficiency and saving efforts. DSM will be a key to achieve energy saving in companies. Electrical energy is one of the main resources used, especially in manufacturing companies. Focus is on resource efficiency all over the world. As an example, the requirement of the EU directive 2012/27/EU is to have energy audits that are mandatory for large scale companies [2]. Estonia as one of the member states has started a program for such audits to be made for large companies (more than 250 employees, or turnover over 50 million Euros, or annual balance sheet 43 million Euros or more). The audits with the deadline of 23.04.2017 consisted of an energy survey divided by energy sources, usage type and energy analyses with participation in training [3], [4].

The complexity of energy efficiency is recognized by the policymakers. The European Commission has released a thematic issue for exploring links between energy efficiency and resource efficiency. The purpose of the thematic issue was to provide an overview of new research on the linkages between energy and resource efficiency to help to inform policymaking in this area. [5]

When focusing on resource efficiency, it is suggested to have different key factors for different sectors to follow the resource use and resulting environmental impact, and energy intensity. Key indicators are given in Table I. [6]

Table I Indicators for resource efficiency by sectors [6]

Sector	**Resource use intensity**	**Environmental impact intensity**
Industry	o energy intensity, o water intensity, o material intensity (direct material input)	o CO_2 intensity; o solid waste intensity, o biological oxygen demand (BOD) intensity; o chemical oxygen intensity (COD)
Manufacturing	o energy intensity, o water intensity, o material intensity	o CO_2 intensity, o BOD intensity, o COD intensity
Household and other consumers	o energy intensity, o water intensity, o land use intensity	o CO_2 intensity, o municipal solid waste intensity, waste water intensity

EU 2020 agenda proposed by the European Commission in March 2010 is as follows: smart growth: developing an economy based on knowledge and innovation; sustainable growth: promoting a more resource-efficient, greener and more competitive economy; inclusive growth: fostering a high-employment economy delivering social and territorial cohesion. The EU has introduced seven flagship initiatives to work towards these priorities. Flagship initiative 4 is Resource Efficient Europe, a Communication adopted on 20 September 2011 that focuses on:

- decoupling economic growth from resource use;
- supporting moves towards a low-carbon economy;
- increased use of renewable energy;
- transport sector modernization and promoting energy efficiency.[6]

Studies made so far have suggested four policy solutions:

- Support EU industries to increase resource effectiveness. By using the right material and by focusing on research development and innovation to introduce alternative materials, new products designs and products with more sustainable characteristics.
- Increase support to material efficiency. Using the material right would entail adopting measures that maximize the use of the 'same material'. This would include recycling, industrial symbiosis, and measures towards cradle-to-cradle approaches.
- Introduce economy-wide eco-efficiency indicators. Measuring resource efficiency at the firm level has given some indications on the consumption of resources, but has not given an indication of the 'level of efficiency' of firms. Therefore, setting efficiency indicators is an important policy tool to manage resources at the EU level.
- Address the current barriers to resource efficiency. [6]

The Europe 2020 strategy includes the target of a 20% increase in energy efficiency by 2020; and resource efficiency has been one of its initiatives. EU Energy commitment has set a target of at least 27% for renewable energy and energy savings by 2030. EU's Energy Union Communication policy focuses on achieving a fundamental transformation of Europe's energy systems by 2030 through energy efficiency. Analyses made so far of energy and resource efficiency are that they normally only compute one of the issues: either energy or resource efficiency. It is generally assumed that increasing energy efficiency will lead to improved resource efficiency and vice versa, but combined analyses are still scarce. In [6] it is stated that significant increases in energy efficiency are a key prerequisite for decarbonizing the EU's energy system and achieving the target of an 80–95% reduction of GHG emissions by 2050. European Resource Efficiency Platform policy recommendations concern the need to increase resource productivity from current levels by an order of magnitude of at least 30% by 2030, and to integrate this approach into the Europe 2020 strategy. Thematic areas for resource efficiency indicators in industry are given in Table II. [5], [6]

Table II Indicators for resource efficiency by resource type [6]

Material Resources	**Natural Resources**	**Energy**	**Waste**	**General**
Consumption of material, (amount)	CO_2 emission reduction per product	Annual energy consumption	Recycled materials to production, (%)	Expenditure of resource related to R&D
Savings of input material excl. water, (amount)	Emissions to air, (amount)	Annual energy savings	Recycling rates	
Saving of input material excl. water), (%)	Reduction of emissions to air, (%)	Amount of fossil fuel required	Waste collection rates (national level)	
	Emissions to water, (amount)	Average therm. efficiency per production unit		
	Reduction of emissions to water, (%)	Substitution of conventional fuels by alternative, (%)		
	Reduction of emissions	Primary energy consumption		
		Savings on primary energy		

Energy audits in company are becoming more complex as the energy is looked as one of the resources in resource audits. Increasing efficiency of the different industries is also supported in EU and its member states. As an example, Estonian Ministry of the Environment has applied a program for companies' energy and resource efficiency increase. The support mechanism is supported by EU 2014 to 2020 budget period and the total supporting budget is 220.7 million Euros. The following four types of activities are supported: increasing awareness, educating specialists, making resource audits and investments to increase resource efficiency. There are targeted companies in small and medium scale and manufacturing industry. Initiatives related with projects for innovative energy and resource efficiency increase or production process redesign are supported. The support mechanism includes regulations for necessary actions to be made and financial and resource usage analyses and monitoring plans. [7], [8] Meeting the requirements enables not only support but more importantly, provide a comprehensive overview of the resource usage and financial analyses of the possible effect of the actions for the companies. DSM, which is a part of the efficient use of electrical energy resource, has increasing importance in different aspects; as described in this section, also through different political actions.

To implement DSM, many obstacles have to be overcome, like changes in energy market regulations to support DSM, changes in consumer mindset and practical methods to apply DSM. Current work provides an approach to solve problems for the last two of them. Change in the consumer mindset is achieved by merging DSM methodology with existing production planning methodology and providing step by step approach for DSM application in the industry sector. The proposed method can be part of the resource audit made in industry or in addition to electrical energy, can be adopted also for other sorts of resource wastes such as waste water, heat etc. as well. Table III summarizes main benefits of demand side management.

Table III Benefits from DSM [9]

Actor	Benefits
Producers	reduced peak-load generation
	less need for peak units
	less need for capacity reserves
	higher share of RES possible
TSO/DSO	lower congestions
	less outages
	lower losses due to an attended load
	lower investments in grid
Market	lower price volatility
	increased demand elasticity
	BRP lower risks for imbalances
Retailers	lower exposure to high price/high demand situations
	new tariff structures possible
Consumers	increased awareness and participation
	possibility to have control on the electricity bill
Environment	increased integration of RES made possible
	reduced GHG emissions through lower use of fossil-fueled plants
	higher security of supply: less fossil imports, more local production

1.2 Main objectives and activities of the thesis

Main purpose of the thesis is to propose a new economic evaluation methodology for DSM applications in the industry sector, based on classical value stream mapping from lean production. The classical value stream mapping methodology should be improved for demand response evaluations in the industry sector and experimentally tested in power generation and supply systems. The proposed methodology should take into account not only static demand response possibilities such as more efficient devices, but also dynamic possibilities, which are the result of load scheduling in industrial processes. ***The main research tasks of the PhD thesis were as follows:***

- to analyze existing evaluation methods for demand side management;
- to analyze demand side management possibilities in industrial processes;
- to develop/improve methodology for estimation of load scheduling possibilities in industrial process;
- to develop/improve methodology for estimation of energy conservation possibilities in industrial processes;
- to test the proposed methodology experimentally in the real life industrial process.

Main hypothesis of research:

- the improved value stream mapping methodology, which takes into account also dynamic and static demand response possibilities (incl. energy intensity and control flexibility), will increase the flexibility of classical value stream mapping methodology;
- the improved value stream mapping methodology could be used for demand response analyses, and companies that already have value stream map can easily adopt demand response analyses in the production management;
- it is possible to achieve at least a 10% cost saving in an industrial process with dynamic and static demand response.

1.3 Contribution of the thesis and dissemination

Theoretical originality of the work:

- research of demand side management possibilities for balancing of power system and forecast errors reduction of renewable power plants (i.e. wind parks);
- development of improved value stream mapping methodology for the evaluation of load conservation in the industry sector;
- development of improved value stream mapping methodology for the evaluation of load scheduling in the industry sector.

Practical originality of the work:

- economic feasibility study of dynamic demand response in an open electricity market;
- analyses of energy price fluctuations in open energy marked based on the example of Estonian energy marked; as a result, economic effect on the demand response in open energy market is given;
- analyses of economic benefits from demand response for the renewable energy producers through the example of load scheduling possibilities for balancing wind parks fluctuating production;
- practical proof of improved value stream mapping methodology by the evaluation of demand side management in the heat production industry.

Novelty:
The current relevance of the thesis is related to increasing unpredictable electrical energy production from renewable energy sources (i.e. hydro, wind and solar) and practical demand response possibilities to provide balance for unpredictable energy productions.
Proposed methodology improves flexibility and reduces the time consumption of energy and resource efficiency analyses in the industry sector. The results would be helpful for the industry operational excellence program facilitators and demand response developers as well as demand side aggregators. The results provide an approach applicable in industry independent of its type or geographical location.

1.4 Thesis outline

The current thesis includes four appended published papers. The thesis includes additional analyses, which have not been previously published. The thesis contains six chapters that are described in brief in the following list.

- Chapter 2 covers previous research and the potential of the DSM in different industries or technologies. It includes the definition of demand side management and explains the difference between dynamic and static demand response. It also explains the new possibilities for dynamic demand side response that are derived from open electricity market and its fluctuating hourly price, indicating demand and supply tendencies in Estonian electricity market. It also describes the methodology used in production management and a possible conflict between production management goals and demand side management.
- Chapter 3 analyzes the benefits of demand side management for the renewable energy production. The outcome is described through direct cooperation of demand response provider and wind parks. The increase of real life cost efficiency from demand side management is calculated in case it is used for balancing wind energy forecast errors.
- Chapter 4 introduces a novel methodology for the evaluation of demand side management. The methodology is based on the existing value stream mapping that is widely used in industries where lean philosophy is applied in real production.
- Chapter 5 tests the proposed methodology in a real life example. The example is provided by the heat production industry and consists of load scheduling and energy conservation evaluation.
- Chapter 6 presents conclusions and recommendations for policy- makers.

This doctoral thesis is based on four published papers of the author of the thesis, which are attached in the Appendix of the thesis. Article I is also referred to in the IET monography.
The thesis research was carried out in the Estonian heat production industry from 2014 to 2017. The thesis contains a reference list which includes 61 different sources.

Abbreviations

AFR	annual constant energy consumption reduction
ASC	available stock capacity
AVR	annual variable energy consumption reduction
BESS	battery Energy Storage System
BMP	balancing market price
BT	buffer time
C/O	change over time
C/T	cycle time
CHP	combined heat and power
CP	cost for process
CPC	cost for increasing process capacity
CS	cost saving
CS	cost for storage
DAP	day-ahead price
DSM	demand side management
DR	demand response
FFC	future constant energy consumption
FI	forecast imbalance
FRR	relative energy reduction of constant consumption
FVC	future variable consumption
GHG	greenhouse gases
HPP	high price period
HPPP	high price period price
HPS	high pressure sodium
HVAC	heat ventilation and air conditioning
IFC	initial constant energy consumption
ILS	income from load scheduling
IR	Infrared
IRP	integrated resource planning
IVC	initial variable consumption
L/T	lead time
LED	light emitting diode
LPP	low price period
LPPP	low price period price
LS	load scheduling
MSC	maximum stock capacity
MV	middle voltage
RE	renewable energy

SSC	secure stock capacity
TSO	transmission system operator
VFD	variable frequency drive
VRR	variable relative energy reduction
VSD	variable speed drive
VSM	value stream mapping

Terms

EU	European Union
TSO	Transmission System Operator

Symbols

BMPP	purchase price from balancing market
BMPS	sales price to balancing market
COSϕ	power factor
C_{RE}	renewable energy producer profit decline
ΔP_i	avoidable losses in a consumer unit
ΔPp	avoidable losses behind a consumer unit
E_{CFI}	annual renewable energy producer forecast imbalance
E_{DSR}	demand response provider forecast imbalance
E_F	forecasted energy production
E_{FI}	energy forecast imbalance
E_m	measured energy consumption
E_{NFI}	minimum negative balanced energy
E_{PFI}	maximum positive balanced energy
E_R	real energy production
E_{RE}	renewable energy producer forecast imbalance
E_{Tot}	total forecast imbalance
F_{Ia}	agreed forecast imbalance compensated by demand side response
h	efficiency
I_f	phase current
I_n	nominal current
L	gas flow
n	number of hours in period
n	device rotation speed
nMAPE	normalized Mean Absolute Percentage Error
P	power
p	pressure
P_a	actual wind park output power
P_d	power used based on designed data
P_{DSR}	nominal power available for demand response
P_f	forecasted wind park power
P_{inst}	installed capacity
P_l	power to cover energy losses
P_m	measured power consumption
P_{mc}	measured power used by the system behind consumer unit
P_n	nominal power
t	time
U_f	phase voltage

Units:

°C	degrees, Celsius
m^3	cubic meters, volume
Wh	watt-hour, unit of energy
V	volt, voltage
h	hour, time
W	watt, active power

Metrix prefix

k	kilo, 10^3
M	mega, 10^6
G	giga, 10^9

2 State of Art Analysis

Following state of art analyses firstly describes the terminology of dynamic and static demand side management; analyses potential and possible drivers for demand side management and also makes overview of the studies made so far. Chapter 2 of the current work is based on paper [II].

2.1 Analysis of static and dynamic demand side management measures

Consumption loads today are more predictable and controllable through smart energy systems, batteries and local production units. This gives opportunities to keep energy systems in balance by active consumer engagement, called demand side management DSM. Consumers can provide services for TSOs as well. In [10] DSM measures are divided into two major categories: static and dynamic (Table IV). Static measures consist of long-term investments to technology to achieve higher energy efficiency; dynamic measures are more related to short-term consumer behavior and are also called demand response (DR). Also, differentiation is made between passive and active measures. Passive measures are achieved through regulations and active measures come from the consumer behavior in situations when market conditions are favorable. In this thesis research, demand side management is referred to as customer actions for the change in consumption. DSM addresses initiatives and technologies that encourage consumers to optimize their energy use. The benefits from DSM are potentially two-fold. Consumers can reduce their electricity bills by adjusting the timing and amount of electricity use and the energy system can benefit from the shifting of energy consumption.

The European Union has given clear guidance to develop demand side management to ensure the use of demand response in energy systems. The Energy Efficiency Directive Article 15.4 requires that Member States remove those incentives in transmission and distribution tariffs that are detrimental to the overall efficiency (including energy efficiency) of the generation, transmission, distribution and supply of electricity or those that might hamper participation of Demand Response, in balancing markets and ancillary services procurement. Also, it is required to ensure that network operators are incentivized to improve efficiency in the infrastructure design and operation, and, within the framework of Directive 2009/72/EC that tariffs allow retailers to improve consumer participation in system efficiency, including Demand Response, depending on national circumstances. Article 15.8 of the directive defines consumer access to energy markets, either individually or through aggregation. The European Commission, Joint Research Centre reviewed the progress of Member States toward opening markets for Demand Response. As the result, the countries were divided into three groups. [11]

- Group 1 consists of countries where the demand response regulation is not seriously engaged. Portugal, Spain, Italy, Croatia, the Czech Republic, Bulgaria, Slovakia, Hungary, the Baltics, Cyprus and Malta were included in the first group.
- Group 2 holds the countries in the process of enabling demand response through the retailer only. They limit aggregators to the role of service providers to retailers. Group 2 includes Germany, the Nordics, the Netherlands and, to a certain degree Austria.

- Group 3 of the Member States enables both Demand Response and independent aggregation. This includes Belgium, France, Ireland and the United Kingdom. [11]

Table IV DSM measures [10]

Type and duration	Static (long term)		Dynamic (short term)	
Energy system level impact	Increasing energy efficiency and to some extent energy savings		Increasing efficiency of market mechanisms; increasing to some extent energy efficiency and energy savings	
Customer behavior	Passive - from regulations or 3rd parties	Active - choice of the customer	Passive - automatically or based on contracts	Active - customer actions
Demand side actions or terminology in use	Energy Efficiency (regulations)	Energy efficiency (customer installs or uses more efficient technology)	Demand Response (DR) initiated by TSO	Demand Response (DR) initiated by energy market
	Energy conservation (regulations)	Energy conservations (consumer limits the use of energy)	Change in demand (ordered by TSO)	Change in demand (based on market price signals)
	Integrated resource planning (IRP)		Regulation of the demand	Real time pricing
	Energy performance contracting			Time of use pricing
				Critical peak pricing
Examples	Energy efficiency standards in appliances	Heating insulations in buildings	Interruptible loads used to provide reserves	Load shifting in response to high price.
Required level of customer involvement.	Low/medium	Medium	High/medium	High
	Participation regulated by regulation or 3rd parties	Consumer's decisions for long term energy conservation	Consumer demand is controlled by 3rd parties	Consumer makes decisions based on market price

DSM is for those sectors where energy efficiency gives sufficient savings. This thesis research focuses on the industry sector where potential is the highest as the consumption units capable of shifting the loads are more powerful. Thus, in the industry sector, the benefits for a single consumer are higher than in any other sector. Thus, the potential for energy saving relies to a great extent in the industry sector as it holds a large share in the total consumption, as shown in Fig. 2.

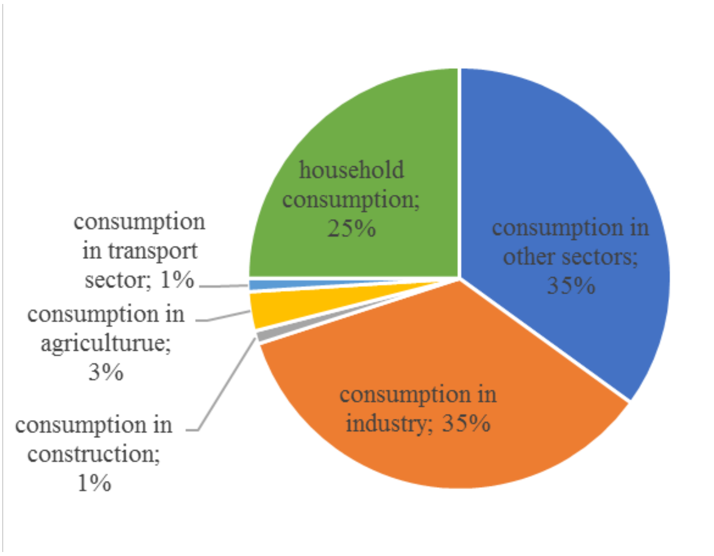

Fig. 2 Share in electricity consumption in Estonia by different sectors 2013 [12]

2.2 Analysis of load shifting evaluation methods and their placement in load shaping strategy

Focus in the thesis is on the dynamic side of demand side management, often called as demand response, and on the static side. In the dynamic side, existing methodology for load shifting was analyzed and improved. Load shifting (sometimes in some context called load scheduling) as a part of DR means that consumption loads are shifted from one period to another. Load shifting is widely studied as the practical use of such possibility would have major effect not only on the consumer but on the whole electrical energy systems.

Previous DR studies have resulted in the following: static Stackelberg game theory for voluntary load curtailment programs [13]; numerical calculation method for DR when a battery energy storage system (BESS) is utilized [14]; solutions for DR by means of automatic lighting [15]; DR with micro combined heat and power (CHP) systems [16]; an overview of DR methods in high consumption industries and examples of market tools that support DR [17]. In [18] an automated complex system for LS in industry is described, which takes into account stock restrictions, maintenance schedules, and crew management. All the necessary inputs are analyzed with a fuzzy/expert-based system combined with an optimization module. As a result, the system is able to identify whether and to what extent the industrial plant can participate in a DR event.

In [19] and [20] DR is addressed as a part of the following main load shaping strategies:

- conservation - energy saving is achieved through static methods;
- load growth - energy consumption is increased when an energy system has surplus energy production;
- valley filling - load is increased through the off-peak periods or keeping stable consumption;
- peak clipping - energy consumption is decreased in peak periods;
- load shifting - peak consumption is shifted from peak periods to non-peak periods;
- seasonal load reduction - annual energy peaks are reduced.

Load scheduling is used mainly in the “load shifting” strategy; however, in some cases, “valley filling” strategy can be utilized as well. The aim of the research is to provide a methodology applicable to dynamic and static demand side management possibilities, by using value stream mapping (VSM). VSM is applicable in various ways. Originating from Toyota Production Systems [21], it was further elaborated and adjusted to find solutions for different problems in the production process. For example, VSM is used to solve quality problems [22]. The VSM is elaborated to use it for indicating a possibility to shift an electrical load from a high price period to a low price period and utilize an intermediate stock for energy storage [23], [24], [25].

Load scheduling (LS) as part of demand response (DR) must meet the needs of industry. One of the effects for the industry appears when load consumption is shifted from periods of high electricity price to those of low price. As a result, cost savings can be achieved by means of reduced consumer demand in high price periods. This requires better production planning, which is related to production management.

2.3 Energy price as a driver for load shifting

LS can yield an economic effect under rational consideration. Cost reduction can be achieved by taking advantage of energy price fluctuations during a day. It is reasonable to have demand response implemented in countries where an electricity pool exists and hourly based spot prices are known for a short period ahead. As a result, industries can plan their production according to the spot price.

Fig. 3 shows an average 24-hour electricity market spot price in Estonia in 2014 [26]. As can be seen, electricity spot price is typically higher from 7:00 A.M. to 8:00 P.M. In general, there is at least 10-euro price difference during a day and a night. Considering the price peak and dip, approximately 20-euro difference per MWh exists during a day. On average, price difference during a day is 15 euros per MWh. [II]. However, these considerations are including only electricity price; in addition, there are some fluctuations in grid service price as well. From 12:00 P.M. to 8:00 A.M. (11:00 P.M. to 7:00 A.M. in winter time), the grid service price is lower [27]. This period is not overlapping 100% with a low spot price period. The period from 12:00 P.M. to 8:00 A.M. is called the Low Price Period (LPP) and the other period during a day the High Price Period (HPP). Grid tariffs depend on grid connection voltage level and connection capacity (amps). In the following, we will describe an example to examine the daily price differences for the industry in Estonia.

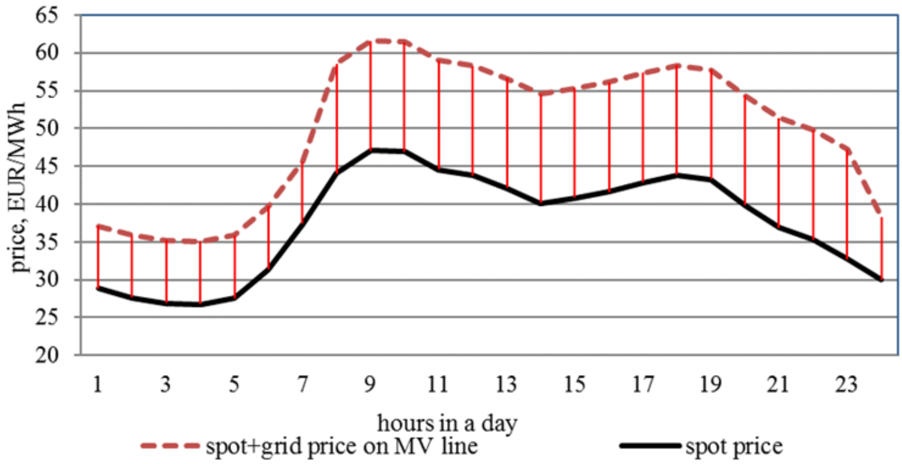

Fig. 3 Average Estonian electricity price during a day in 2014

At substantial electricity consumption, an industry is usually connected into a middle voltage (MV) grid. In that case, Estonian major grid company service price is 14.5 euros per MWh in HPP from 8:00 A.M. to 12:00 P.M. and during LPP 8.3 euros per MWh [27]. For some customers, no time difference is applied; the price for grid services is constant in time - 12 euros per MWh. Fig. 3 shows both the grid price and the spot price fluctuations.

In 2014, an average electricity spot price for LPP was 29.5 euros per MWh and with grid price fluctuations it amounted to 37.8 euros per MWh, which we call the Low Price Period Price (LPPP). In 2014, an average HPP spot price was 40.9 euros and together with grid tariff, the average number was 55.1 euros per MWh, which we call the High Price Period Price (HPPP). For clarity, 55.1 euros is an average found on hourly bases, i.e. spot price + grid price. There are constant differences in grid price structure. For example in November 2017, one of the major district heating companies in Estonia changed the price structure significantly. This has to be kept in mind when making investments to demand response, as the bases of the economical calculations can be influenced by the price structure of the grid company. However, the principle of having higher prices in the high consumption period is in general typical.

Based on the data provided, we can calculate potential savings for industry under LS. Potential cost saving (CS) is 31%, which is calculated by (1):

$$CS = \frac{HPPP - LPPP}{HPPP}. \qquad (1)$$

In general, it can be concluded that grid tariff fluctuation has an important role in LS in Estonia, as the average difference in the spot price between HPP and LPP was 11.4 euros per MWh and grid tariff will add extra for the difference between HPPP and LPPP; according to [27], tariff depends on the grid connection parameters.

The shape of the electricity spot price in Fig. 3 can be considered as a typical shape of the daily demand of electricity as well; a similar shape of demand can be found in various places, e.g., even in South Africa [28]. Thus, DR has a positive impact on the overall efficiency of the energy systems, not only on an industry itself.

2.4 Value stream mapping methodology for production efficiency increase

Previously, in section 2.2, VSM was shortly described. This section explains VSM in more detail for further development of the energy efficiency and gaining benefits from fluctuating energy prices, as described in the previous section.

Today lean production is a leading production management philosophy. VSM is used to plan production as efficiently as it is reasonably possible. Value stream mapping is a process-mapping method that enables organization:

- visual representation of existing operations (information and product flows)
- to identify the largest sources of waste (non-value added activity) in the value stream
- to draw a future state map as a vision of the value stream in the future.

Lean philosophy is used in many kinds of organizations. Therefore, the term value stream has to be used; in the production facilities, the value stream can be narrowed to the production processes flow in one production facility. Fig. 4 shows a typical value stream map for the production.

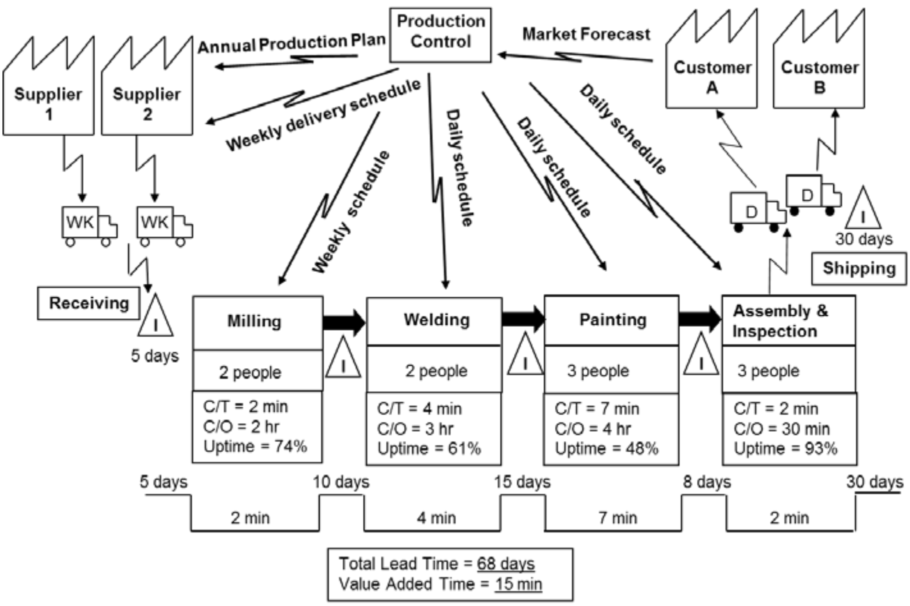

Fig. 4 Typical value stream map for production evaluation in an initial state. [29]

Each process flow has its important parameters shown in the following list:

- C/T- cycle time shows the time in the production process that it takes to move the material or work in progress through the production cycle. In other words, cycle time is the starting time when an operation begins to the point of time when the operation ends. In most processes, it includes process time, inspection time, transportation or movement time, and wait time. For example, if material is painted in batch of 5 pieces during a 5 minute painting process, then the cycle time of one piece is 5 minutes, although 5 pieces are made in 5 minutes.

- C/O - change over time shows the time when it is required to make changes in the production process to produce another kind or product or type of product. As an example from the cycle time, if we produce one type of product in the paint shop and we need to change the color of the product, then the change over time shows the time of changing the color in the paint shop.
- Uptime - shows the process reliability or availability. If the process has a lot of unexpected stops, then the percent of the uptime will fall.
- Lead time - is the total period of the production process that starts when a request is initiated and ends with delivery.
- Value added time - is the part of the C/T when actually the same additional value is created; it does not include waiting time, transportation time, inspection time etc.

The most important parameters in the value stream map are the value adding time and total lead time. In most cases, the ambition is to reduce the lead time of the production so that the cost of the material would be transformed as fast as possible into the goods that are sold.

2.5 Conflict between production goals and demand response in the industry sector

In the last decades, industrial companies are focusing on the economic efficiency of the production, which includes reduction of any activity that does not create value for the company. One of the most used approaches to achieve this goal is using the lean manufacturing methodology in production management. In that methodology, non-value added activities are called waste. Most of the research related to lean production focuses on one or two elements for finding out the existence of non-value adding activities and suggests their views on implementing these elements. Lean principles define the value of the product as seen by the customer, every action in lean manufacturing must be in-line with the customer need called as pull and strive for perfection through continuous improvement actions. The goal is to sort out value added activity. The pull method mentioned means that production information and actions are not controlled in central production management but information moves in the production lines according to the needs of the customer. Non-value added activities considered in the lean methodology are as follows: transportation, inventory, motion, waiting, overproduction, over processing, and defects. One of the tools available to reduce the non-value added activities is value stream mapping. This is a methodology to define a value stream, which includes activities in the production process that are required to convert raw materials into customer needed product, including material and information flow. The value stream map includes both value-adding and non-value adding activities. [30], [31]

In the application of value stream mapping, one of the non-value adding activities is reduction of stock amounts, as this results in the waiting times in the process, additional costs for inventory and the work-in process. By using value stream mapping, it is possible to reduce production costs and speed up the manufacturing process.

Production profitability is more dependent on the customer stable demand; changes in demand or product type, might result in additional costs for the inventory or work-in process that are not needed any more. Resulting costs in the production are converted slower to the product paid by the customer. For example, results in [32] showed that the use of this method allowed reducing the duration of the production cycle for 42.28%, the cost of products – by 57.71%.

Lean manufacturing trends can have negative influence on the DSM part using load scheduling. The primary goal of load scheduling in the demand side management is to shift the loads in time as needed by the energy system or energy market and DSM is expected to reduce the need for investments in the networks and power plants in order to meet peak demands [33]. This can be seen as an aspect conflicting with the lean principles since the production plan has an additional input besides the customer need. This might be one of the aspects for industrial companies to be reluctant to look for DSM as one of the solutions to increase profitability. Effects of demand side management that might restrict the use of it in the production process load scheduling are given in the following three points:

- Effective load scheduling might increase the intermediate stock amounts, as scheduling takes into account energy market or energy system needs besides the customer need.
- The process with high energy consumption might need additional investments to increase production capacities. As the process following the high energy consumption process is faster, scheduling cannot be implemented without increasing production output.
- In extreme cases, the biggest energy consumer is also the biggest investment to manufacturing and the whole production process is planned based on this energy consumer; in lean manufacturing this means that the consumer is a bottleneck in the manufacturing process. It often results in the situation where the biggest investments are kept running maximum possible hours and cost savings in energy do not cover possible return of the investment running hours.

This thesis research uses improved value stream mapping in order to see the possible restrictions and opportunities. Improvement of the existing methodology enables other possible incomes on the production to be seen as well as to find positive effects of an inventory inside the manufacturing process on the company. All this information in the value stream map enables integration of the customer value adding activities and demand side management.

3 Economic Feasibility of Demand Response

Demand response, a part of dynamic DSM, provides opportunities for the renewable energy sector to balance unpredictable production. Unpredictable production is the main problem for the RE production development as the RE production such as wind and solar is unpredictable and can have negative effect on the energy system stability. Current economic effect from demand response can come from price fluctuations, as described in the previous chapter. On the other hand, this does not take into account the effect in case DR is used also for the balancing of RE unpredictable production. In this chapter, economic feasibility of DR is analyzed, which is gained from the balancing effect of RE producer. Chapter 3 of the work is based on paper [I].

3.1 Analyses of wind parks forecast imbalance

The share of renewable energy in the total electricity production is rising continuously worldwide. Renewable energy (RE) producer has a need for DR. This comes from the fact that in the open energy market, RE producer has to plan the energy production one day ahead. Forecast has to be made for short periods, for example, in the Nord Pool Stock, the forecast must be on hourly bases. In case the energy produced is less than the forecast, the RE producer needs to buy additional energy from the balancing market. If the production is higher than the forecast, the RE producer will sell the produced energy to the balancing market, usually at a lower price. There will be a decline of profit from the difference between the forecast and the real production, which is called forecast imbalance (FI). Eq. (2) shows the calculation to find the energy of FI (E_{FI}), which is the difference between forecasted energy production (E_F) and real energy production (E_R).

$$E_{FI} = E_F - E_R \tag{2}$$

Our focus will be on the possibility to reduce profit decline from FI with DR. Profit decline will appear at particular hours when E_R is differentiated from E_F and as a result, a need for a fast and direct co-operation between RE producer and DR provider arises. If there is direct co-operation, DR must have fast reaction time for balancing the RE production. DR provider will benefit from the service and can utilize cheaper energy, which is the result of the FI. A good example for the RE producer is a wind park that has always FI as the wind is not so well predictable. DR with fast reaction time can be provided, for example, by the electric boilers with heat storage or industrial processes that can be shifted in time. In the following, a solution is provided for wind parks to have DR in direct cooperation for the reduction of costs related to production forecasting errors. The FI of the wind parks is analyzed. It is needed to estimate the DR potential. Also, economic effect on the DR is calculated for balancing wind parks and an overview of DR solutions and energy storage requirements is given.

Many articles address an accurate forecast of wind park output power. Reference [34], for example, gives a model for short term wind speed predictions with artificial neural networks. An approach proposed in [35] presents a technique for short term wind power forecasting using a hybrid intelligent system, [36] on the other hand, gives more generic framework for wind power forecasting. This thesis research involves three different wind parks (located in different regions in Estonia). Wind park production is forecasted in two steps. First, the availability for each turbine is taken into account. Availability of the wind turbines for the next day is planned a day ahead in order to provide on time production plan to the electricity spot market. Availability is forecasted on hourly basis. As the second step, the wind park availability plan is given to the production estimation. Production estimation takes into account turbine stop times, wind meteorological forecast in the wind park location and turbines production curves. Turbine production estimation also takes into account historical data for error correction. Nevertheless, the energy production forecasts are not 100% accurate. Table V gives an overview of the share of E_{FI}. In paper I, wind parks are named WP-A, WP-B and WP-C and the period analyzed is from 1 October 2014 until 30 September 2015. We can see from Table V that all three wind parks have a significant share of energy sold or bought from the balancing market.

Table V Share of wind parks forecast imbalance from real production

Wind park	**E_{FI} from total E_R, %**	
	E_F<E_R	***E_F>E_R***
WP-A	16	17
WP-B	13	14
WP-C	10	23

In order to describe the accuracy of the forecast, normalized Mean Absolute Percentage Error (nMAPE) given in [37] with Eq. (3) was used:

$$nMAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{P_a - P_f}{P_{inst}}\right| \cdot 100\% \quad (3)$$

where P_a is actual wind park output power, P_f - forecasted wind park power, P_{inst} - installed capacity of observed wind park and n - number of hours in the period. [I]

nMAPE for the total Estonian installed wind power capacity in [37] is given as 6.07% for the period 01.06.2012 to 30.05.2013. In our case, the corresponding numbers for three wind parks are 8.02% for WP-A; 7.02% for WP-B and 6.74% for WP-C. The higher numbers can be considered normal as the cumulative error is smaller than each and individual wind park. For example, by calculating nMAPE for three wind parks cumulatively, we obtain 5.15%. With DR, FI can be supported even better than just cumulating all forecasts together. In that case, DR provider will forecast production as well and can reduce or increase its production according to RE FI in an equal opposite amount. Service provider has also obligation to plan its load accurately so that FI is equal to 0 in case DR service is not needed. The DR can balance FI of the RE producer with opposite load imbalance, as shown in Eq. (4)

$$E_{DSR} = E_{RE} \cdot (-1)\,, \quad (4)$$

where E_{DR} is DR provider FI and E_{RE}- RE producer FI. In case RE producer and DR service provider have made a common balancing region, then from the balance management point of view, total FI is equal to the sum of the RE producer and DR service provider FI, as shown in (5).

$$E_{Tot} = E_{RE} + E_{DSR}\,, \quad (5)$$

where E_{Tot} is the energy of total FI.

Table V showed the share of produced energy that could be balanced by DR. To have 100% DR for that energy, the DR capacity must be equal to the nominal power of the wind park. From a practical point of view, the maximum needed capacity of FI from wind parks is not reasonable as the maximum is seldom used. Financial calculations in each individual case must be made to find optimal DR capacity. To establish the optimal capacity, the annual utilization of the DR in an agreed amount has to be found. It is reasonable to examine the use of DR capacity from its representation on the graph, which shows duration in hours when E_{FI} is to be balanced in nominal DR capacity. For three wind parks, this is given in Fig. 5.

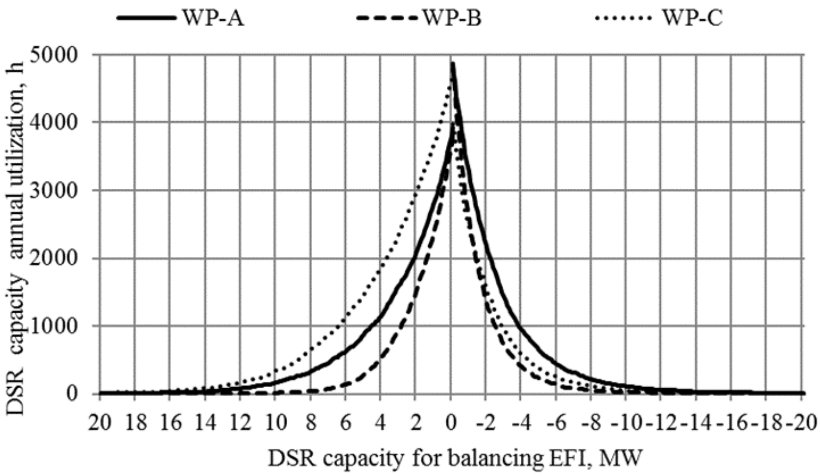

Fig. 5 Annual use of DR capacity for three wind parks.

In the current analyses, to ensure good utilization, DR capacity equal to hourly average FI from wind parks was used. Table VI shows average FI from three wind parks.

Table VI Average forecast imbalance from wind parks

Wind park	**Average E_{FI}, MWh**	
	$E_F<E_R$	$E_F>E_R$
WP-A	-1.36	1.47
WP-B	-0.86	0.91
WP-C	-0.94	2.2

To provide DR for full FI, the capacity required is more than 10 times higher than in the case of DR provided for the average FI. Also, based on Fig. 5, we can say that almost every hour there is a need of the DR for the wind parks. Table VII shows a period (t_{FI}) in a year when FI can be balanced with DR nominal capacity, which is equal to average FI of wind parks. Utilization time is not the only one, nevertheless, it is an important parameter for calculating an economic effect.

Table VII Duration of average forecast imbalance

Wind park	**Duration t_{FI} of average E_{FI}, h**	
	$E_F<E_R$	$E_F>E_R$
WP-A	2732	2531
WP-B	2686	2564
WP-C	2431	2906

To estimate the effect of proposed DR capacity, the annual E_{RE} that can be balanced by DR (E_{CFI}) is found using (10). In case $E_F>E_R$, then:

$$\text{If} \quad E_{FI,i} < E_{PFI} \text{ then } E_{FI} = \sum_{i=1}^{n} E_{FI,i} \ , \tag{6}$$

$$\text{if } E_{FI,i} \geq E_{PFI} \text{ then } E_{FIn} = \sum_{i=1}^{n} E_{PFI,i} \ , \tag{7}$$

in case $E_F<E_R$, then:

$$\text{if} \quad E_{FI,i} > E_{NFI} \text{ then } E_{FI} = \sum_{i=1}^{n} E_{FI,i} \ , \tag{8}$$

$$\text{if } E_{FI,i} \leq E_{NFI} \text{ then } E_{FIn} = \sum_{i=1}^{n} E_{NFI,i} \ , \tag{9}$$

$$E_{CFI} = E_{FI} + E_{FIn} \ , \tag{10}$$

where (i) is an hour in the overall period, the period is defined by (n), E_{PFI}- maximum positive balanced energy by DR and E_{NFI}- minimum negative balanced energy by DR, E_{FIn} - sum of applied E_{PFI} or E_{NFI}, as given in (7) and (9) respectively. In our analyses, E_{NFI} equals average negative FI and E_{PFI} equals average positive FI by a wind park. The results are given in Table VIII.

Table VIII Balancing capacity and percent from total FI at the DR size equal to average wind parks FI

Wind park	**Balancing capacity, MWh**		**Share from total FI, %**	
	$E_F<E_R$	***$E_F>E_R$***	***$E_F<E_R$***	***$E_F>E_R$***
WP-A	-4976	4632	41.8	36.0
WP-B	-3148	2872	41.8	35.9
WP-C	-2952	8186	35.8	42.4

3.2 Demand response possibilities and energy storage requirements for reduction of forecast errors

As we have shown, there is a significant amount of FI and positive effect can be achieved when applying DR to decrease it in the wind parks. Several DR systems such as hydro power stations can be applied, as described in [38]. Also, more complex systems are analyzed in [39] where thermal power, hydro power and flow batteries are used for hybrid power balance control. In [40] it is even proposed to have a small-scale hydro power station for storing energy during low price periods and releasing it at high price periods. As stated in [41], the back-to-back approach does not often take into account the operation of power system in the energy market and its economic efficiency. Back-to-back approach is described as a system where wind power is used to fill up the storage during high wind periods, and the storage energy is used when there is no wind. In the proposed DR, with direct cooperation between RE producer and DR provider, some special aspects should be considered. These include a need to provide DR within the same hour when FI is appearing, so that DR reacts almost online to FI errors. DR has to have accurate load forecast, take part in day-ahead energy market and it needs to be efficient in converting energy. For those particular restrictions, electric boilers with heat storage can be a suitable DR provider. This system in aggregated form is described in [42] where controllable electric water heating and storage systems cooperation under control for DR is given.

The application of DR described above requires energy storage in different forms. Next, we analyze energy storages required for correction of wind parks FI. Energy storage capacity required depends on the time necessary to cover the FI. For the participants in the Nord Pool Stock day-ahead market, the production plan has to be made at 12:00 PM for the next day [43]. So every 24 hours, DR provider can adjust its energy load plan according to energy storage fulfillment. This, however, is not sufficient, as it does not take into account the period for the time when the next production plan will come into force. If the plan is made for 12:00 PM, then we have to take into account the period to the end of the day as well. As a result, energy storage must have a sufficiently large size to balance FI at least for 36 hours. DR provider has to have energy storage available for the end of the day when planning is made for 12 hours and 24 hours for the new planned period. With a forecast change it is possible to plan to empty or to fulfill heat storage in order to keep optimal storage amount. If the longest period to store the energy by DR into energy storage is 36 hours, the energy required to store (Es) in storage can be found with (11) and (12).

$$E_S = \frac{P_{DSR} \cdot t}{\eta} \tag{11}$$

and

$$P_{DSR} = FI_a \cdot 2 \tag{12}$$

where P_{DR} is nominal power for DR, FI_a - forecast imbalance that is agreed to be balanced by the DR, t - time period for required by FI and η - efficiency of the energy storage. It is required to multiply FI_a with 2 as there is a need to have storage both sides for surplus energy and for lack of energy. In case the P_{DR} equals FI_a, DR provider can only balance the energy when RE producer EF is more than E_R, in that case, DR will stop using energy equal to FI_a. In case E_F is less than E_R, DR is required to increase its energy usage. To cover this case as well, it is required to increase the load of DR equal to FI_a (at maximum). As FI requires the DR load to be increased, it is optimal to keep storage half full to ensure storage of the increased load.

3.1 Economic effect of wind parks from demand response

This section focuses on the economic perspective. Calculations made are based on the three wind parks and Estonian electricity market, which is part of the Nord Pool Stock. In case DR service provider has direct co-operation with the RE producer, DR can have positive effect only if it reduces costs for the RE producer. Positive effect comes from the fact that the RE producer suffers under the decline of profit from the energy that is wrongly planned and forecasted to the market. Next, we will look the difference of the energy prices between planned, i.e., day-ahead prices (DAP) and unplanned, i.e., balancing market price [BMP]. In order to find out the economic effect, it is required to find out price differences between BMP and DAP. It must be pointed out that BMP is not always more expensive than DAP and there is a difference for the producer if one buys or sells the energy with BMP. In the case of selling to the balancing market, the BMP was more expensive than DAP in 3017 hours, i.e., 34% of the time. In the case of purchase from the balancing market, the BMP was more expensive than DAP in 4581 hours, i.e., 52% of the time. In case BMP is cheaper than DAP and the RE producer has to buy from the balancing market, the energy due to FI the RE producer will have an increase of profit instead of a decline. Also, if the BMP is higher than DAP and the RE producer has to sell

some of the energy with BMP due to underestimation of the energy production, the RE producer can have an increase of profit. Balancing market trade is managed by TSO and is separate from the stock market. Without manageable electricity production, the RE producer needs to use the service from the balancing market and does not know if it is more beneficial to forecast more or less. In the study of three wind parks, it was found that they have a decline of profit. A possible profit increase was also taken into account in the calculation; however, in total, wind parks still lose profit from FI.
RE producer profit decline C_{RE} is calculated by Eq. (13):

$$c_{RE} = (\sum_{i=1}^{n}(BMP_{S,i} - DAP_i)\cdot E_{FI,i}; E_{F,i} > E_{R,i}) + \\ + (\sum_{i=1}^{n}(BMP_{P,i} - DAP_i)\cdot E_{FI,i}\cdot(-1); E_{F,i} < E_{R,i}) \quad (13)$$

where $BMP_{P,i}$ is the energy price if there is a need to purchase from the balancing market, $BMP_{S.i}$ – the energy price if there is a need to sell to the balancing market, i – a particular hour when the transaction is made, and n - the number of hours in the analyzed period. DR can reduce the decline of profit; however, the effect from it must be found hour by hour and after BMP is known. To show the economic effect that DR can have to FI, we have calculated an average profit decline per one MWh of FI, shown in Table IX.

Table IX Average profit decline CRE from wind park FI per MWh

Wind park	**Average profit decline C_{RE}, EUR/MWh**	
	$E_F<E_R$	$E_F>E_R$
WP-A	4.39	4.12
WP-B	6.12	6.19
WP-C	12.58	3.05

In section 3.1, the average FI from the wind parks was calculated. Next, we will evaluate the decrease of profit decline through DR with the capacity equal to average wind parks FI. DR capacity is of WP-A 1.47 MW, WP-B 0.91 MW and WP-C 2.2 MW. Fig. 6 shows the result of the economic effect of DR implemented in a given capacity.

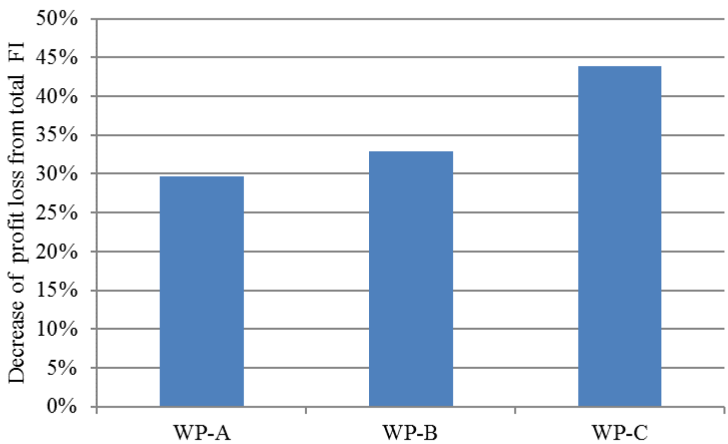

Fig. 6 Profit decline of wind parks through DR.

As was shown, an economic effect exists and DR service provider can increase its economic efficiency by helping to decrease profit decline from FI of the wind parks about 30 to 44%.

This part of the thesis addresses one of the ways to apply and benefit from DR. It is proposed to reduce FI of the RE producer such as wind park by DR. The solution is different from traditional DR solutions where the aim is to reduce the cost of energy purchases. It requires direct cooperation with the DR provider and the wind park. Direct cooperation means that the DR provider and wind park are planning the energy production and consumption together and the DR provider needs to act if it appears that the production forecasted by the wind parks is not the same as the real production. There are some benefits from direct cooperation for the DR provider as the DR provider has no need to participate in the energy balancing market directly and those requirements are not applicable, as an example requirement for the minimum capacity. DR provider can reduce the profit decline of the wind parks from FI. Profit decline can be from 3.05 to 12.58 euros per MWh in the case of the three examples provided. About 30 to 44% of the profit decline from the total FI profit decline can be reduced with the DR capacity equal to an average wind park FI. The DR provider must control its consumption in two ways, meaning to increase or decrease energy demand, as the forecast of the wind park can be less or more from the real energy production. In the two-way consumption control, the DR provider is required to have double DR capacity compared with wind park FI, which is agreed to be balanced. As a result, we can state that the solution provided shows the economic positive effect of DR for the wind parks and makes it possible to use DR in a small scale whereas the wind parks are in many different sizes.

4 Development of Static and Dynamic DSM Evaluation Method Based on Value Stream Mapping

As previously shown, a DR provider can provide economic effect for the RE producer and can benefit from energy price fluctuations during a day. In real life, the demand response activities are not often used. The reasons are related to difficulties to see the possibilities for it. In the following, the objective is to find an existing methodology used in different productions. Also, the aim is to supplement the existing methodology with a novel approach for the implementation of the demand response by applying load shifting, energy conservation, and peak clipping strategies.

4.1 Improvement of value stream mapping methodology for evaluation of load scheduling

Focus in this section is on the possibilities to improve value stream mapping. In general, value stream mapping has a potential for usage for the load scheduling as well. This is because it brings out the whole value chain in the production process and the elements necessary for load scheduling. Those include the following: internal stock amounts and production speed in different production cycles. Next, load scheduling possibilities are examined for intermediate storage use as an energy saving unit, to enable shifting of energy intense production from high price period to low price period. In the load scheduling, it is important to understand energy intensive production units and their overall role in the production. Value stream mapping as a method from lean philosophy [LP] can be used here.

4.1.1 Overview of load scheduling possibilities in production

To use the LS, an industry must have the following one or several demand response options, as shown in Fig. 7. These are: cooling equipment with cooling storage, heating equipment with heat storage, dual fuel systems that can operate either on electricity or on an alternative fuel, discretionary loads and process equipment that can be shifted during a short period or material handling equipment with storage possibilities (silos, stock, etc.) [14].

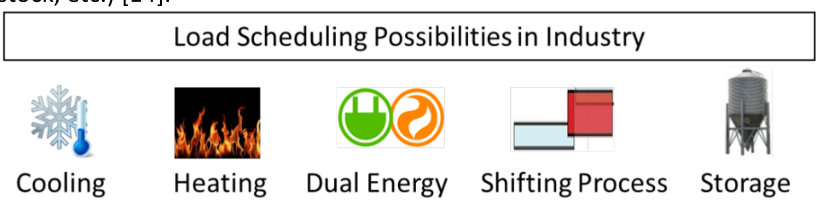

Fig. 7 Demand response enablers in the industrial process.

In addition to the industry specific demand response options, it is possible to use special energy storages that are not industry specific. Battery energy storage systems (BESSs) similar to those shown in Fig. 8. are used to store electrical energy into a special storage system equipped with battery units. That kind of systems can be specially designed for the load scheduling. Such systems enable energy cost reductions and energy savings through saving electrical energy at a high price period and also at high loads (peak periods) when limitations to peak consumption are applicable. Special optimization models are used to manage effectively battery loading and unloading. It is required to take into account physical parameters of a battery, such as battery discharging efficiency, battery charging efficiency and admissible depth of the discharge in order to keep lifetime of the battery. BESS has some benefits regarding fast optimization as well. In general, we can divide optimization into two systems: first, planning day ahead to optimize energy planning if the cost of energy is known one day before. In addition, BESS can be used for fast optimizations one hour ahead, for example, to cover unexpected events in energy consumption. [14]

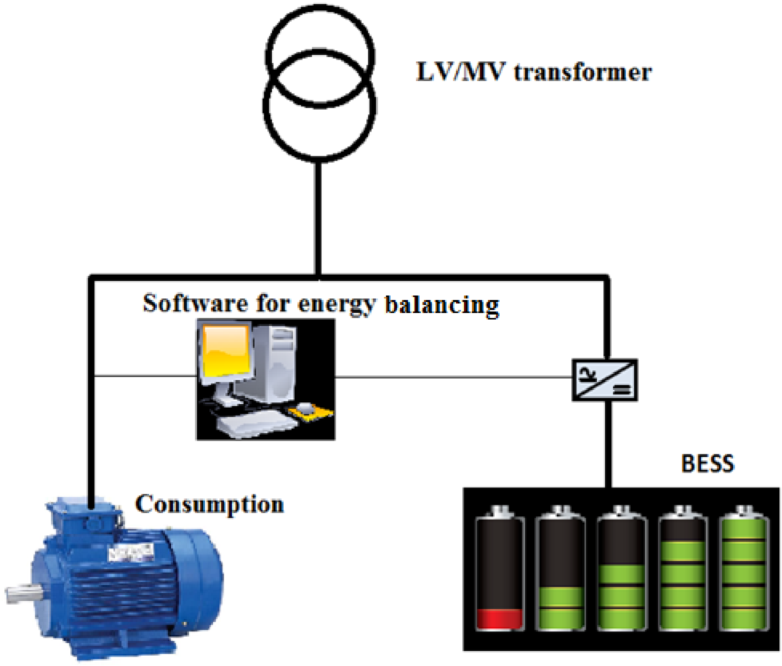

Fig. 8 Battery energy systems for scheduling the load demand from network.

The negative side is that battery energy storages are relatively expensive and they have remarkable losses during the loading and unloading process. This thesis research proposes a novel approach to use the production process and its intermediate work in the process storages as a kind of energy storage.

In the production process as a whole it is possible to find LS solutions that would occasionally not need large scale investments. Focusing on the process, internal stocks and process scheduling might bring low-hanging fruits for the industry in load scheduling implementations. Load scheduling in the production process is possible in every kind of production where the intermediate stock is available. In general, manufacturing is usually divided into five different types, as shown in Fig. 9 [44], [45].

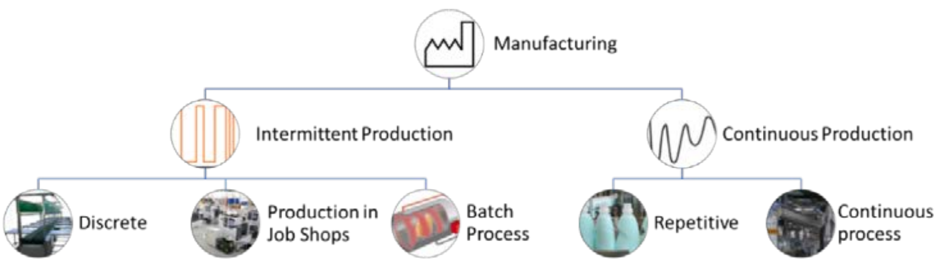

Fig. 9 Types of manufacturing processes.

There are two major differences in the production processes, i.e., a process can be either intermittent or continuous. Intermittent production has stops during the process while continuous has none. The main factors defining the the process type as either intermittent or continuous depend on the cost of the production stop and the end product of the process. In case there are different end products or variations in one type of the end product that requires changes in process or machinery, then there is a need for the intermittent production process.

Intermittent production can be divided into three subtypes. Firstly, there can be discrete production, which has process lines where changes are made often. There can be only few setups and changeovers in the process or frequent setups and changeovers, either way production has its stops time to time. As a result, the end products can be similar with small variations or highly disparate. In the case of huge variations in the products, the unproductive set-up and tear-down time may be long. This type of manufacturing can even be project based. The main difference from the next type job shops is that there are production lines in place.

Job shops have no production lines, they have cells or production areas in the production layout. One cell may produce only one version of a product or many versions. This kind of production is necessary when there are huge variations in the production and there is a small enough back log, so that it is not possible to have lines for similar end products. One example is different wire assemblies with a small amount of deliveries like low voltage switchgears for automation.

In a batched process, operations are similar to discrete and job shop with one major difference. Batched process has some main production units which define the process speed and work in the process amounts to what moves from one activity to another. An example of such equipment is autoclaves. Usually large-scale autoclaves in the production process are the main production unit and the batch size is defined with the amount of products in one autoclave. Also, the process speed is defined mostly with heating up and cooling down of the product in the autoclave. It can happen that one batch meets one customer demand or it takes several batches. The equipment which defines the batch, like the autoclave, is sometimes also cleaned for the next production run so that there are stops in the process.

The next two processes are of continuous type; the first can be called a continuous process. In the continuous process, production is running all the time both day and night. Usually it has some stops for the maintenance yearly. Usually production materials are gases, liquids, powders, or slurries or in some cases they can be granular or chunky materials. Also, energy product like heat and electricity is a typical continuous process. The process can have peak and base load but they never stop as the stop time is either expensive or has long shut down or warm up periods

The last one is a repetitive process. It is similar to the previous one with an exception of having one-piece flow. It has dedicated production lines that turn out the same item, or a closely related family of the product. The line is working continuously both day and night. It can be fully automated or with some manual manufacturing as well. It is continuous for similar reasons as the previous - stopping the line is either expensive or has a long stopping period. An example can be found in milk production. The operations speed may differ to ensure that production has peak and base loads as well, dependent on the customer demand. It is required to have few setup and changeover activities involved. There can be many production lines for one product, which are started and stopped based on the demand; however, the starting and stopping of the lines are usually for a long period, usually from one week to several months.

Manufacturing in a repetitive process, job shops and discrete process are usually found in mechanical, electromechanical, electronic, and software-driven hardware products. Manufacturing can be continuous or intermittent. In case the production process is highly repetitive, then it is most likely that the production process is highly automated as well. In such case, production personnel rarely touch the product and their role is to oversee the equipment, make quality checks and assure that the production equipment functions properly [44]. In practice, different types of the production can be used in one product manufacturing and there are usually some intermediate stocks of the production process used in practice.

The load scheduling can be used in all five different manufacturing types. Focus in the current work is on the intermediate stocks as an energy storage possibility. Intermediate stocks in the industrial process are considered as a kind of energy storage. To connect this with the beginning of this section, we address the material process handling. In case intermediate stock is available, the load scheduling is in principle possible. Certainly it should be kept in mind that in real life, the economic and technical reasons can influence practical use of the load scheduling. In case of intermittent production, the load scheduling possibilities are more natural; however, in the continuous process it is also possible to practice load scheduling as a demand response. The current work shows that load scheduling examples of the continuous heat production process where fuel has some intermediate stock and load scheduling can be applied using fuel conveyors load controlling. To use intermediate stocks as an enabler for load scheduling, it is necessary to understand what will happen in every part of the production value chain. Next, a novel methodology is developed for using production intermediate storages together with necessary understanding of the process value chain when adapting load scheduling in the production process.

4.1.2 Methodology improvement for load scheduling with value stream mapping

Current section of the work has been prepared and presented in paper [II].

Value stream map gives an overview of the production planning as described in section 2 and can additionally give information about energy intensity. By improving VSM with energy consumption data it is possible to understand energy intensity in addition to the process flow. This thesis research proposes a novel methodology for analyzing load scheduling possibilities in the production and for improvement of the value stream mapping (VSM) methodology with load scheduling principles.

Energy intensity can be added in a process as additional information for a value stream map. The novel approach enables us to detect the waste of energy in the production process to apply static and dynamic DSM initiatives. From the DR side, the possibility of the load scheduling can be studied in detail. The value stream map contains all important information for load scheduling, such as process time and intermediate stock amounts. For example, it can be detected if an energy intense process is at the same time a bottleneck in production. If it is not so, then the conclusion is that this process is not 100% utilized in time and load scheduling can be implemented without increasing the process capacity. Alternatively, costs for increasing process capacity (CPC) need to be calculated.

Focus will now be on the intermediate storages. Processes before the storage consume energy, most of which is useful; there can be some waste or unnecessary loss of energy as well. This thesis research focuses on those in the following sections. If the process is not a bottle-neck in the flow, it gives a certain freedom to decide when the process starts and ends in time. At the same time, stock consists not only of the product but also of energy used during the process before the stock. Thus, the process internal stocks can be seen as energy storages. It is necessary to emphasize that if production is shifted in time, storage volume can increase as compared to the state without load scheduling utilized. This change can be very well outlined in the value stream map. Storage increase may need additional investments, which should also be considered as costs for storage (CS). Also, costs of the process (CP) itself for LS should be taken into account. As an example, CP related to LS can be an increase in labor costs due to night shifts. Finally, if the costs related to LS are lower than a possible income from LS (ILS), the LS can be implemented in the industrial process. This criterion is given in the following (14):

$$CPC + CS + CP < ILS \tag{14}$$

The main initial goal of lean production and value stream mapping was to reduce lead time (L/T), i.e, the time it takes to move a produced piece all the way in the process or production from start until the end. As a result, many costs or wastes, as defined in lean philosophy, will be reduced. As given in (14), income from load scheduling should be higher than costs related to it because load scheduling can increase the intermediate stock and due to that it has a negative effect on the lead time as well. VSM is a tool that will help to find the processes that have a reasonable effect and income. To achieve that, cost saving potential must be estimated.

Possible gain from load scheduling was shown in Chapter 3. The next step is to define the energy consumption of the processes. It is useful to combine that with the value stream map. As lean philosophy and value stream mapping are widely used in production management, a production company already can have a value stream map. In that case, energy consumption should be added into the value stream. In case a company does not have it, the value stream map should be made from scratch. As mentioned previously, a value steam map will highlight important information to be considered for load scheduling. Most importantly, the following information must be taken into account:

a) Identify if the process is a bottleneck in production. If the process is a bottleneck, then load shifting is usually impossible without investment into the process output increase.

b) Process cycle time (C/T) is slower or faster than its next process C/T. If the process C/T is slower than the process coming next, it is possible to increase intermediate stock at the end of the process coming after rather than at the end of the first process. In case the first process is faster than the next one, the LS applied will increase the intermediate stock.

c) Whether a process uptime is high or low, it shows important information about process reliability. A low reliability process has negative effect on load scheduling.

d) If the stock between the processes is high or low, the reasons should be found out before applying load scheduling.

e) Change over time (C/O) is long or short. It can show also time for cold start of the process. C/O can highlight important information about the process start up time.

The best way to start defining the energy consumption of a process is to make the consumer list. The consumer list should be based on the processes described with VSM. The consumer list may be available in the facility electrical department. In that case, the consumer list is usually based on the power cabinets and it has to be made process by process. If the consumer list is not available, it should be done from scratch. As the purpose is to find an initial energy intensive process, the consumer list can be composed without actual measurements. The initial consumer list should contain the following minimum information: process description; rated power; $\cos_{\phi}$; nominal current (I_n); nominal efficiency η and consumption type that can be either continuous, intermittent or stand by. In addition, the measurements need to be made to obtain average measured power consumption (P_m). For load scheduling, the energy consumption (E_M) for processing one or agreed amount of product must be measured as well; this data can be added directly to VSM. An example of a consumer list is given in Table X.

Table X Consumer list

Description	P_n	Cos φ	U_n	Consumption type	η	P_m	E_M
Process A	…	…	…	Continuous	…	…	
Process B	…	…	…	Intermittent	…	…	
Process C	…	…	…	Stand by	…	…	

Upon completion of the consumer list, traditional VSM should be elaborated and average loads and energy consumption in the process added. As a result, elaborated VSM will show which processes have sufficiently high energy intensity to gain benefits from LS and on the other hand, to estimate the particular potential to the process scheduling. As the energy usage can be estimated based on installed nominal power P_n, measurements can be done in the production process where energy usage is estimated to be high, in this way, it is possible to reduce time on the processes where the effect for the load scheduling is not significant. On the other hand, in case the value stream map shows that load scheduling can be implemented without investing to process capacities or intermediate stocks, also processes with low energy consumption can be studied as the implementation costs can be low in such processes. Fig. 10 gives an overall picture of a typical value stream map elaborated with process energy intensity and amount of energy stored in the production intermediate storage.

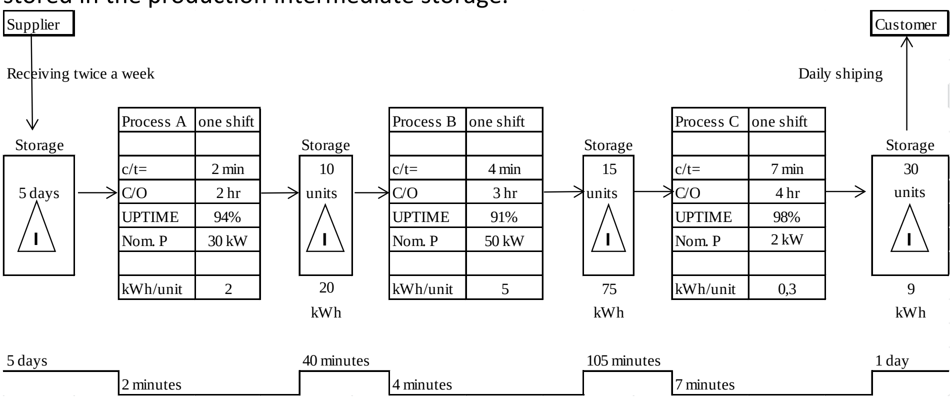

Fig. 10 VSM with energy consumption and storage overview.

As the value stream map describes the product flow, the energy intensity should also be given per product or production unit. The unit energy consumption in the production process should be calculated based on the actual measurement. Fig. 10 shows a theoretical example of VSM together with data from the consumer list and energy intensity in the process. Energy intensity is energy consumption in each process to make one unit. As can be seen, the process A C/T takes 2 minutes, i.e., one unit is completed during 2 minutes in the process. The total nominal power of the process is 30 kW and 2 kWh is consumed to make one unit. First intermediate stock capacity (after process A) is 10 pieces. It consists of 20 kWh energy available for scheduling. Process B C/T is 4 minutes and the total nominal power in that process is 50 kW. As the second intermediate stock (after process B) capacity is 15 pieces, it has 75 kWh energy available for scheduling. Process C cycle time is 7 minutes, total nominal power is 2 kW and 0.3 kWh is consumed for making one unit. We can see that the process A C/T is two times faster than process B and process C cycle time is 3.5 times faster than process A. As a result, we can conclude that the last process will dictate the whole process time and previous processes can be scheduled taking into account the possibilities of the last process. For that reason, we need to know how much time it takes to empty the intermediate stock before the slowest process, which we call buffer time (BT). In order to find BT, the process C/T must be multiplied with an available intermediate stock capacity (ASC) (15) and (16).

$$ASC = MSC - SSC \tag{15}$$

$$BT = C / T \cdot ASC \tag{16}$$

ASC is a difference between maximum stock capacity (MSC) and safety stock capacity (SSC). SSC is to be defined by production management.

BT shows the maximum load scheduling period in the process. Neglecting safety stock capacity, in our example, BT is 105 minutes. The total energy we can shift during 105 minutes is 95 kWh, which is the sum of stored energy in two intermediate stocks with 75 and 20 kWh accordingly.

4.2 Improvement of value stream mapping methodology for evaluation of load conservation

Section 4.2 of the study is based on paper [IV].

In addition to load scheduling, the value stream mapping provides a unique possibility for the load conservation and peak clipping as well. In the following, the methodology for energy conservation and peak clipping is developed further. A future value stream map is created, which contains the process and product flow after applying load conservation or peak clipping strategy in industry. The possibilities for the implementation of the conservation and peak clipping strategy have been widely studied for specific consumption units for the energy conservation strategy. The studies show the efficiency of different technologies and compare them. For instance, in [46] LED lighting is described. Among other topics, the efficiency of LED lighting is analyzed. An example of lumen and watt correlation in different lighting technologies is illustrated. Paper [47] describes an example based on the industrial facility lighting, [48] and [49] concentrate on the efficiency of electric motors, in [50], solutions for efficient HVAC systems in the high-tech industry were proposed. These studies explain well the energy savings for different specific technologies.

4.2.1 Overview of load conservation and energy efficiency possibilities in production

In the following, load conservation and energy saving possibilities in industry widely used today are described in brief.

Variable frequency drives (VFDs) are the most common application for energy saving; however, VFD is not always used for energy saving purposes as a main reason. Sometimes it is used to acquire flexible start up and continuous regulation of the electrical motor. Energy saving is a side effect and it holds still a significant value. The efficiency dependency on the frequency has been widely studied and it has been found that with partial load, it has good effect on motor efficiency. The results show that it is best to use an example of pumps and ventilation systems. Affinity laws state that the fluid or gas flow (L) provided by fan or pump is dependent directly on the device rotation speed (n), as given in (17):

$$\frac{L1}{L2} = \frac{n1}{n2}, \tag{17}$$

pressure (p) is square dependent on the rotation speed, as expressed in (18):

$$\frac{p1}{p2} = \left(\frac{n1}{n2}\right)^2, \tag{18}$$

and the power input (P) is a cube dependent on the rotation speed (19):

$$\frac{P1}{P2} = \left(\frac{n1}{n2}\right)^3. \tag{19}$$

Voltage control enables us to achieve greater voltage quality by using special transformers in the demand side. With voltage quality increase, it is possible to increase consumer unit efficiency. Voltage control is more widely used in countries where voltage quality in the main network is in poor condition. Also, it is possible to adjust the voltage according to the load of the induction motor, which is one of the largest energy consumers in industry. The efficiency of an induction motor will decrease in case the load of the motor is less than the nominal load. It is possible to increase the efficiency of the partially loaded induction motor by reducing the voltage. In general, the loads where voltage reduction will have its effect on the efficiency must be less than half of the nominal load. As an approximate example with rated voltage, the efficiency of the inductive motor will decrease to 50% when the loads are approximately 30% from the nominal load. With voltage reduction up to 60% from the nominal voltage, the efficiency with the same 30% nominal loading will be approximately 80%. That kind of methods are considered less expensive than variable frequency drives [51]; however, it has its limitations and can be used when constant speed is required.

Electrical energy consumption units also require reactive energy. Reactive energy will increase the costs in the distribution networks and are usually charged with fees. Consumers can install reactive energy compensators that compensate reactive energy consumption of the consumer unit. Typical reactive energy consumers are electrical motors. Reactive energy compensators are usually installed in the main connection point of the facility with the network or near the main reactive energy consumption units usually together with large nominal power. Effectiveness of the reactive energy compensator depends on the cost of reactive power. Reactive energy compensation, together with variable speed drives is one of the widest spread energy saving methods in Estonia.

Lighting saving is also a widespread energy saving method and can save energy up to 8 to 16% of energy saving with passive control. Passive control is an automatic system when light is switched off automatically based on the timer or IR and movement sensor. With intelligent light control, when the control of the lights is combined between the timer, IR and movement sensors, daylight dimming and lumen control, the savings the inventory stock and meeting rooms can be 45 to 65% [52]. Together with light control, it is required to consider the replacement of lights with more efficient ones. Table XI will show the potential saving and type of the lights dependency. With lights replacement, also better reflection of the light and light leading into the room must be considered. With old lights replacement, with better reflection effect and better light leading into the room, the energy saving can be up to 35% because of the reduction of the lights amount in room [52].

Table XI Potential saving at different light replacements [52]

Initial lamp	Energy Label	Replacement lamp	Energy Label	Potential saving
Incandescent bulb	E,F,G	luminophore	B	65-80%
Incandescent bulb	E,F,G	halogen	C,B	25%
Incandescent bulb	E,F,G	LED	A	80%
Halogen	D,E,F	LED	A	70-80%
Luminophore	D,C,B	LED	A	25-50%

Finally, the role of consumer side energy production is increasingly important. It has increased as new technologies are becoming available. Also, energy tariffs are more sophisticated and often drive consumer to consumer side energy production. Typical consumer side production units are solar panels or small-scale CHPs, usually gas engines. The benefit comes from either reduction of demand in general or due to restrictions of the peak loads. In addition, the usage is increasing as many countries provide subsidies for such solutions or for renewable energy solutions in general.

4.2.2 Methodology for load conservation and peak clipping with value stream mapping

In section 4.1, the methodology for DR was described. In the methodology, a consumer list was made where actual measurements of the energy consumption are included. The consumer list and measurements addition provide necessary data for understanding the static demand side managment possibilities. Next, the focus will be on the energy saving possibilities on the consumer side independent of the specific technology. Consumer side energy conservation or peak clipping means that it is necessary to increase the energy efficiency of the process; in practice, the losses or waste of energy can be reduced. Fig. 11 presents the proposed methodology approach for reduction of losses in three different aspects.

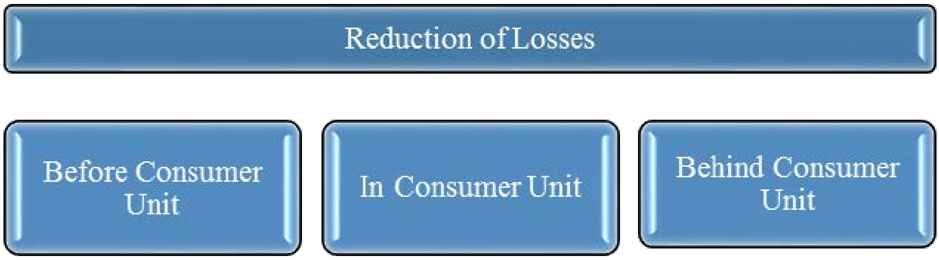

Fig. 11 Reduction of losses for energy conservation and peak clipping

a) Reduction of losses before the consumer unit contains losses related to energy transfer from commercial energy measuring point up to consumer units. For example, it considers losses in cables, transformers and other elements in the supply network, starting from the distribution cabinet with a commercial energy meter.

b) Reduction of losses in the consumer unit. This aspect focuses on the consumer unit. The purpose is to detect less efficient technologies, such as inefficient motors, lighting, cooling and heating devices. We propose to list the consumer units in the consumer list, which allows definition of the efficiency of each unit. These efficiencies should be estimated based on the technical documentation or measurements of the devices. For example, by means of the measurements, it is possible to detect the correct dimensioning of the consumption units such as electrical motors. It is required to study reduction of losses from inefficient control. Control systems of devices and electrical motors should be detected; as a result, more efficient controlling solutions such as variable speed drives (VSD) can be used.

c) Reduction of losses behind the consumer unit is losses in the process. For example, if the process behind the consumer unit is a compressed air system, solutions to increase the efficiency of the system by reducing losses in the pneumatic system can be applied.

4.2.3 **Enhancement of the consumer list for energy conservation and peak clipping**

To estimate the potential of conservation or peak clipping, the future value stream map should be made. This means that in addition to having the energy intensity in the value stream map as shown in section 4.1, the possible reduction of the energy consumption should be shown in the future state of the value stream map. As the consumer list in section 4.1 was made for conservation and peak clipping purposes, the consumer list should additionally contain the following additional data given in Table XII.

1. η is the efficiency of the consumption unit in operation, for example, the efficiency of a motor, heating unit or lighting systems. The approach addresses a specific type of a consumer unit; for example, we consider light system efficiency, which is watts per lumens delivered to the target area. This means that loss in reflectors and trapped light are also considered.
2. ΔPi is avoidable losses in a consumer unit; these can be, for example, coming from inefficient control of the devices or from efficiency decrease due to wrong dimensioning.
3. ΔPp is the process loss behind a consumer unit, which can be, for example, losses in compressed air systems or losses in conveyors. In efficiency calculations, comparison with the designed requirements should be made.

Table XII Example of enhanced consumer list [IV]

Description	P_n, kW	Cos φ	U_n, V	Consumption type	η, %	P_M, kW	ΔP_i, kW	ΔP_p, kW
…	…							

After completion of the consumer list and VSM with energy consumption data, possible solutions for energy conservation and peak clipping strategy can be detected. As a result, cost-effective future VSM can be constructed. The future VSM should contain an action plan, showing initiatives for load shifting and conservation strategies. Energy conservation can consist of savings in variable consumption, i.e., consumption that varies together with the processed goods and in fixed consumption, i.e., consumption that is independent of the processed goods. For this reason, value stream map should contain the following data for a good overview of static demand side management possibilities:

- IVC- initial variable consumption;
- FVC- future variable consumption;
- VRR- variable relative energy reduction;
- AVR- annual variable energy consumption reduction;
- IFC- initial constant consumption;
- FFC- future constant consumption;
- FRR- relative energy reduction of constant consumption;
- AFR- annual constant energy consumption reduction.

The example of the novel method for the implementation of demand side management initiatives with an enhanced value stream map is shown in Fig. 12.

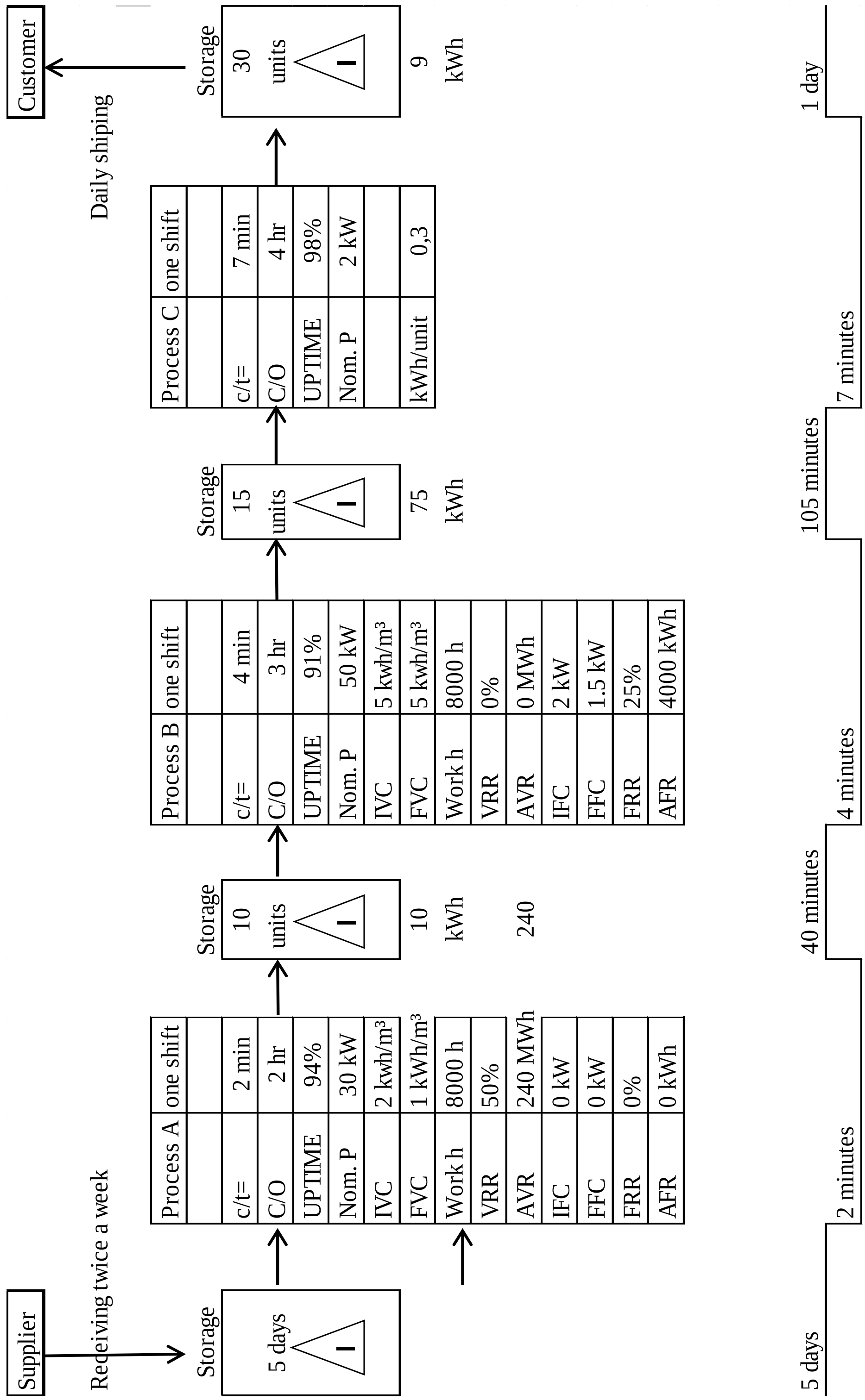

Fig. 12 Value stream map for static and dynamic demand side management possibilities.

As a conclusion, the flow of the process of implementing load scheduling from the demand response side and energy conservation or peak clipping from the static demand side management side is shown in Fig. 13. The flow will provide comprehensive and novel approach to the VSM by applying this method for the energy as a resource audit.

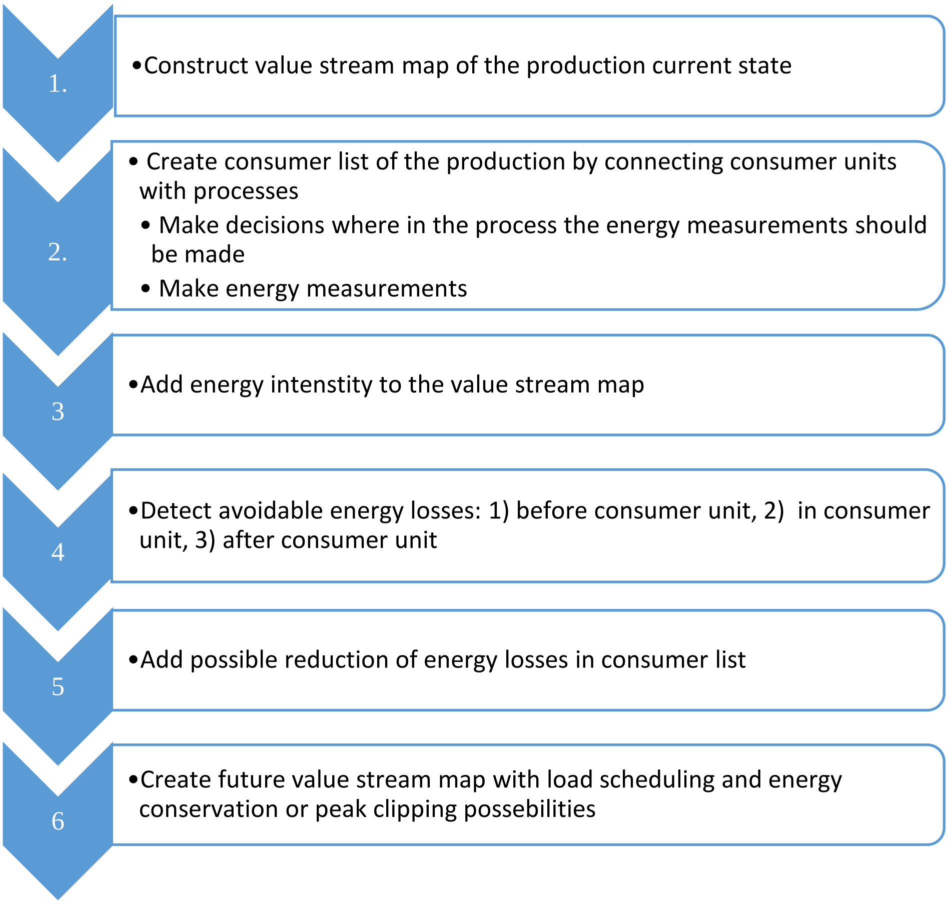

Fig. 13 Improvement of value stream mapping for demand side managment.

5 Experimental Implementation of Improved VSM Methodology for Evaluation of Demand Side Management Possibilities Based on District Heating Plant

Chapter 5 of the study is based on paper [IV].

In the following, an example of the proposed methodology is shown. The example is based on the heat production units, which involve continuous production with continuous processes. The consumption of the units is not significant; however, in an aggregated way, the possibilities of demand side management are much greater. In Estonia, for instance, 2 425 GWh of heating energy was produced by woodchip boilers [10], which is more than 70 times higher than in our example. This example covers a district heating plant. The company has one 8 MW woodchip boiler, several boilers fueled with shale-oil and one CHP plant based on woodchips and with 8 MW thermal, 2 MW electrical output. Below an experimental example of the methodology is presented based on the proposed steps in Fig. 13 in the previous section.

5.1 Production unit value stream map

The example of the novel methodology of value stream mapping for the demand side management is based on the 8 MW biomass boiler production unit. This example was chosen because the boiler has a large daily silo, providing an intermediate stock and due to that it has load scheduling potential. Fig. 14 shows the value stream map of the 8 MW woodchip boiler of the plant. Woodchip boiler stock (moving floor) is filled by a conveyor from the main storage (moving floor). The main storage is filled by the incoming trucks or a wheel loader. The company has 5-day storage available on site. Woodchip boiler stock can contain woodchips a day with the boiler nominal load, i.e. 180 m^3. The conveyor between the main storage and the woodchip boiler stock has a designed nominal output of 50 m^3/h. The conveyor from the woodchip boiler stock to the boiler can be considered continuous processing, as its output goes to the woodchip boiler. As the boiler has small (less than 1 m^3) storage to or daily silo available between the boiler and the conveyor, the output is 7.5 m^3/h with the nominal boiler load. We started the cost reduction estimation from load scheduling by modeling the process using VSM as a basis. One cubic meter of woodchips is taken here as one unit in the value stream map.
According to the conveyor output parameters, the total output time of 1 m^3 of woodchips is 6 days and 17.2 minutes and the value creating time is 16 minutes. In the value creation time, all unnecessary transportation only time for feeding the boiler were excluded and the boiler burning process is considered the value creation time in this example. Uptime is considered 95% with unexpected stops and condition based boiler cleaning. As the created value stream map in Fig. 14 shows, the conveyor from the main to the boiler stock has excessive capacity and is able to process 1 cubic meter of woodchips approximately 6.67 times faster than the process bottleneck, i.e. woodchip boiler. The boiler will process 1 cubic meter of woodchips into heat in 8 minutes. It can be concluded from VSM that there is a possibility of load scheduling of the conveyor from the main storage to the boiler stock. It must be emphasized that we deal with a biomass conveyor; therefore, the following simplifications were used:

a) woodchip processing by a boiler is calculated based on the nominal load, and boiler efficiency parameter is 0.8;

b) woodchip energy intensity is approximated at 1.3 MWh/m³, in real life it can be different, based on the fuel type and humidity level.

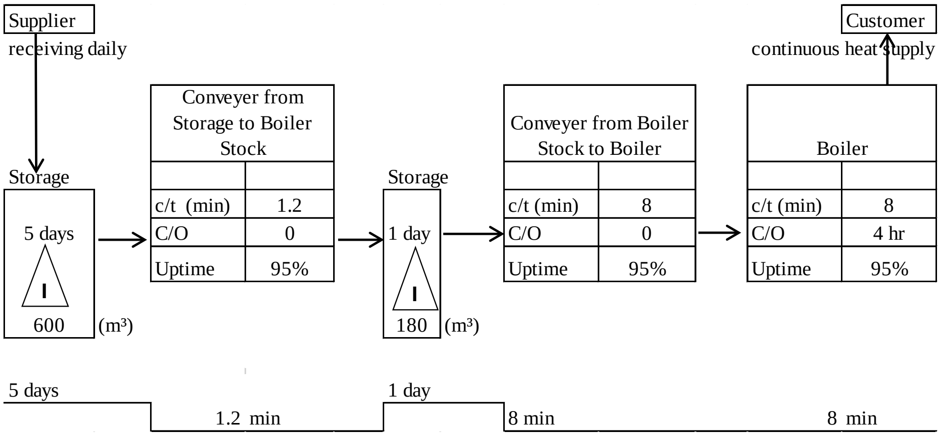

Fig. 14 Current state value stream map of woodchip boiler

5.2 Consumer list and energy measurements of the example

The next task is to estimate process energy intensity by making a consumer list behind the process. In the example, it is evident from the current state value stream map that the only process that can be scheduled is the process called "Conveyor from Main Stock to Boiler Stock". Thus, we need to make a consumer list behind this process, which is given in Table XIII.

Table XIII shows that the total nominal power behind the process is 73.5 kW. The consumer list is necessary to estimate the process energy demand. It is possible that some consumer's nominal power is much greater than the actual absorbed power. Therefore it is necessary to measure the process energy use.

Table XIII Consumer list of the example

Description	Pn	*Cos ϕ*	In	Un	Consumption
Conveyor screen to dist. conv.	15	0.8	46.9	0.4	Continuous
Distr. conveyor	7.5	0.8	23.4	0.4	Continuous
Floor to conveyor motor	4	0.8	8.6	0.4	Continuous
Floor to conveyor motor	4	0.8	8.6	0.4	Continuous
Hydro pack	15	0.85	28.9	0.4	Intermittent
Hydro pack	15	0.85	28.9	0.4	Intermittent
Screen	5.5	0.81	11.4	0.4	Continuous
Conv. floor to screen	7.5	0.8	23.4	0.4	Continuous

In the example, Fluke 1735 was used for measurements of the process energy use and current measurements for some continuous consumption. Absorbed power was calculated using Eq. (20):

$$P = 3 \cdot I_f \cdot U_f \cdot \cos_{\varphi} \tag{20}$$

where P is absorbed power, I_f - phase current, U_f - phase voltage and $\cos_\phi$ is the power factor. By using absorbed power for a continuous load, energy consumption was estimated as well. Total energy consumption for processing 1 m³ of woodchips was 0.96 kWh. Complete VSM for the process examined is given in Fig. 15.

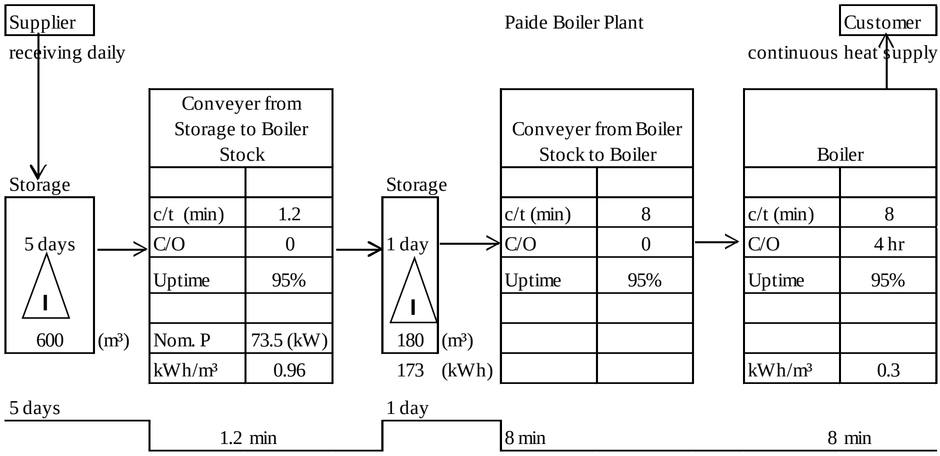

Fig. 15 VSM for LS for district heating plant

The VSM shows that by processing 1 cubic meter of woodchips, 0.96 kWh of electrical energy is consumed. As there is storage available with 180 m^3 and SSC is 7.5 m^3, ASC is 172.5 m^3 using (15). By knowing the process C/T behind the intermediate stock, it is 8 minutes per m^3. Thus, BT is 23 hours by using (16).

We can conclude that BT is sufficiently long for considering LS from HPP to LPP given in Chapter II. Boiler plant is connected to a grid at low voltage line, so the grid tariffs applicable will be different from those given in Chapter 2. HPPP for the current example is 83.4 euros per MWh with 43.5 euros per MWh grid tariff and LPPP is 55.2 euros per MWh with 25.7 euros per MWh grid tariff. Based on (1), we can calculate potential saving, which is 33.8%.

As stored energy in the process is 0.173 MWh, by multiplying that with HPPP, the cost for the company will be 14.42 euros per day and saving from LS will be 4.88 euros per day.

In the previous example, the VSM process is not complicated; however, VSM is essential in case production is more complicated and processes are more complex and dependent on each other. In that case, VSM enables cost savings with LS. Moreover, LS is well understandable with VSM for staff involved in production management and planning.

5.3 Load conservation and energy efficiency analysis in a district heating plant with improved VSM methodology

In the previous section, value stream map was made for the wood chips boiler and energy intensity was added to the map. The load scheduling possibilities were found and the value stream map was shown. To plan future actions in the production regarding energy savings, it is required to study not only load scheduling initiatives but energy conservation possibilities as well. The future state value stream map should additionally show the conservation possibilities as well. In the following, an analysis of the energy conservation possibilities in the production process is proposed. To apply demand side management in production it is required to give an overview and explain the solutions available. To define the energy consumption of a process, previously, the consumer list was made. As a result, the VSM elaborated showed which processes have sufficiently high energy intensity to gain benefits.

In the following, we explain in more detail the load conservation strategy. The experimental load conservation strategy for the process in Fig. 15 is called a conveyor from storage to the boiler stock. We explain the conservation strategy application by the experimental example. The method proposed approaches in three aspects shown in Fig.11, starting from finding losses before the consumer unit, in the consumer unit and behind the consumer unit. The result of the consumer list is given in Table XIV and explained in the following sections.

Table XIV Consumer list for conveyor between main stock and boiler stock

Description	P_n, kW	Cos φ	U_n	Type	η	P_M, kW	ΔP_i, kW	ΔP_p, kW
M301- conveyor from screen to distribution conveyor	15	0.8	0.4	Variable	87.7 %	2.7	0.14	0.64
M302- distribution conveyor	7.5	0.8	0.4	Variable	85.9 %	1.4	0.07	0.64
M1008- leveling roller	4	0.8	0.4	Variable	85.1 %	1.99	-	-
M1004- leveling roller	4	0.8	0.4	Variable	85.1 %	1.99	-	-
M1000- hydro pack	15	0.85	0.4	Variable	90.6%	9.09	-	-
M1001- hydro pack	15	0.85	0.4	Variable	90.6 %	11.87	-	-
M1003- screen	5.5	0.81	0.4	Variable	89.4 %	5.67	-	-
M-1005- conveyor from moving floor to screen	7.5	0.8	0.4	Variable	87.7 %	3.08	-	0.69
HID lamps	2.2	-	0.4	Constant	25 lm/W	-	1.67	-

5.3.1 Losses before the consumer unit

First, it is required to find saving possibilities for energy conservation in a local electricity distribution system between the distribution station and the consumer unit. Distribution stations should contain commercial measuring points for the energy consumption coming from the distribution system operator. Fig. 16 shows the distribution system for the consumer units given in Table XIV. Distribution losses consider losses in the lines and transformers from the commercial energy measuring point up to the consumption unit. Losses can be calculated based on the load measurements and components specifications of the distribution system. Losses for the lines and transformers can be calculated based on the engineering handbooks or using special calculation software. Another possibility is power measurement between the interconnection point and the consumption units. In most cases, distribution losses cannot be calculated for each consumer unit, as the distribution system may supply many consumer units.

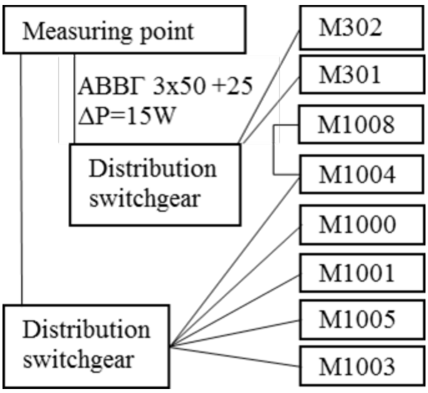

Fig. 16 Example of the distribution system

As shown in Fig. 16, consumer units in our example are using two main lines to distribution switchgears. The measuring point is on the low voltage level. For that reason, there are no transformers in the transmission system. The losses in the lines are minor, i.e., calculated losses are less than 1 W with one exception. The line supplying two conveyors M301 and M302 has old type aluminum cable; as a result, power loss is 15 W. Table XIV shows that the power used on this line is 4.1 kW, which makes the loss of energy on the line 0.35%. 15 W power loss is not significant from the economic point of view for investments to change the cable in use. Thus, no actions need to be planned to reduce the distribution losses. In other cases where consumption loads are high and energy distribution systems contain also transformers, solutions for energy conservation can be applied.

5.3.2 Reduction of losses in the consumer unit

The second aspect of the three energy conservation possibilities focuses on the reduction of losses in the consumption unit. We propose to use the consumer list shown in Table XIV for detecting a technology that is less efficient. The goal is to estimate ΔP_i- avoidable losses in the consumer unit. These losses can be avoided by changing to a more efficient technology or by better control and operation of the consumer units. We propose a three-step approach to estimate the losses in the consumer unit.

Step 1 In the process, some consumer units are not directly related to the process output; moreover, their usage can be related to many processes such as lighting. From the process point of view, their energy usage is constant. For constant energy consumption units, it should be estimated how much of the consumer unit usage is related to the process. It is needed to have correct data in the consumer list, which are process dependent.

Step 2 Technology efficiency is given in Table XIV as E_c should be estimated. Efficiency should be measured; if measurements are difficult in practice, it can be calculated. Calculations can be done based on the design documentations of the consumer unit.

Step 3 After energy usage is known, possible solutions for energy savings in the consumer unit should be estimated; in Table XIV it is described with ΔP_i. Energy savings can be achieved by installing a more efficient technology or a better operation of the consumer unit.

In our example, we have shown energy savings for two consumer unit types: electrical drives and electrical lighting. Table XIV gives the designed efficiency η of each consumer unit; in the following, we will explain how ΔP_i is found.

5.3.3 Reduction of losses in electrical drives

In step 1, all the motors in Table XIV are directly related to the process output; thus, their consumption is not constant from the process point of view. In step 2, motors have at least IE2 class according to standard IEC 60034-30-1. In step 2, we estimate the energy efficiency of existing consumer units. Some motors function at low efficiency because of overdimensioning. Table XIV shows that the measured load of consumer units M301 and M302 is remarkably lower than the nominal power. From Table XIV we know that the installed power is 15 kW and 7.5 kW; however, measured actual power is under 2.7 kW and 1.4 kW, accordingly. The measured power is given in Table XIV under the P_m column. We can conclude that motors are about five times overdimensioned. In a similar way, it is possible to find over- dimensioning of other consumption units. Overdimensioning is the result of lower efficiency. Motors are working at 19.07% from the nominal load. There are several methods available for the motor efficiency measurements, based on the standards such as in [53] or scientific like non-intrusive in [54]. Motors in our example are highly overdimensioned and due to that function at low efficiency level. According to [55], efficiency of the motor loaded 20% is about 5% less than in the nominal power. In step 3 in our example, we can conclude that the designed efficiency decrease of the motors is as follows: M301 from 92.3% to 87.7% and M302 from 90.4% to 85.9%. Lower efficiency contributes to the power losses in the consumer unit. For M301 with 2.7 kW load it is 135 W and for M302 motor with 1.4 kW load it is 70 W. In addition, the efficiency decrease from the consumer unit operation should be estimated as well. For example, VSD increases the efficiency of electrical drives by allowing motors to be operated at the ideal speed under any load condition. In many applications, VSDs reduce a motor's electricity consumption by 30–60% [56]. In the case of an industrial consumer, the load depends strongly on the load factor of the electrical machines, remaining around 50% to 60% from the rated power for mechanical processes [57]. In [55] it is reported that the efficiency of the motor is highest when it operates under 60 to 100% of the nominal load. Efficiency will decline when the motor operates under 50% of the nominal load. In [58], the choice principles for VSD are given and it is stated that thermal considerations of motor operation with a VSD should be of primary attention when choosing a VSD solution. The application of a VSD to a variable torque load such as a fan or centrifugal pump is more suitable, but constant torque or constant horsepower loads can cause motor overheating at reduced speeds. In the current thesis example, the conveyor application has no need for variable speed and the torque for the motors is independent of the motor speed. Thus, it is not suggested to change direct starting to VSD.

5.3.4 Reduction of losses in electrical lighting

The last row in Table XIV considers lighting. It is sometimes difficult to estimate lighting in the production process, as it is often related to many processes and other supporting activities such as safety issues. As lighting can involve significant savings, it cannot be ignored in the estimation of energy consumption. When lighting is estimated in the processes, the quantity of lighting needed for the process and that for other processes should be determined. Furthermore, it should be taken into account that lighting is not always consumed when a process is activated. Sometimes consumption is independent of the process production output. In our example, lighting consumption is not related to the production process output. It is needed for safety reasons at night time, at annual heating periods. As the first step, we have considered only the part of lighting that is needed for conveyor lighting. In our case, there are seven lights involved in the process. The lights are high pressure sodium (HPS) type with a consumption load of 2.2 kW. In the second step, we estimate the efficiency of installed lights. According to [59], installing LED lights instead of HPS lights delivers 76% of the system efficiency. LED lights deliver about 100 lumens per watt. In the third step, we estimate a more efficient technology. We can consider that LED technology is over three times more efficient and only 0.53 kW installed LED lights are needed to obtain the same lighting effect [59]. This results in 1.67 kW of savings in lighting, as shown in Table XIV. The energy efficiency increase from better light operation has not been considered in the current example, as the lights are turned on due to safety instructions in the conveyor area.

5.3.5 Reduction of losses behind consumer units

Conservation strategy can be implemented by means of reducing losses behind the consumer unit. To find out losses behind the consumer unit requires detailed knowledge of the systems. The basic idea behind estimating many kinds of losses is in the comparison of the designed or calculated consumption and actual measured power consumption. The difference between the two will define the losses behind the consumer unit, as expressed in (21):

$$P_l = P_{mc} - P_d \tag{21}$$

where P_l is extra power to cover losses behind the consumer unit, P_d is the power calculation made based on the design data of the system and P_{mc} is actual measured power used by the system behind the consumer unit.

To find out losses in the conveyors and ΔP_p, Table XIV presents the designed power need for the conveyors and compares it with the measured power [60]. To find P_{mc}, we have measured the consumption unit load (P_m). Consumer unit efficiency denoted by η was found in the previous section. P_{mc} that considers the efficiency of the consumer unit was calculated by Eq. (22):

$$P_{mc} = P_m \cdot \eta \tag{22}$$

In our example, P_{mc} equals 0.84 kW for M1005, 0.67 for M302 and 0.45 for M301. Based on (25), we can calculate the power loss behind the consumer unit, which is 1.96 kW, 26% from the measured power Pm. Losses in the system for the other units in the consumer list are not considered significant. This is because M1003, M1004 and M1008 have circulating rollers and losses there come mostly from the faults of the bearing or faults of the transmission gears. Such faults can be detected by making vibration measurements; however, in our example, no faults were detected. For hydro power units, no leakages or malfunction of the devices were detected, so the system losses compared to the design were not found.

5.3.6 Static and dynamic demand management potential in the example

Above, we have shown the example of energy conservation possibility based on the woodchip conveyor process. Table XV shows the potential of the conservation strategy in a concentrated way. As can be seen, results of three energy conservation methods are presented. The table does not consider the economic reasons and shows only the potential.

Table XV Potential energy conservation with future VSM

Reduction of losses	Description	Conservation potential, kW
In supply	Line supplying M301&M302	-0.015
In a consumer unit	Overdimensioned motors and lighting efficiency	-1.63
Behind a consumer unit	Conveyor inefficiency	- 1.96

In section 4.1, we showed the possibility for load scheduling and in section 4.2 our methodology for the implementation of the energy conservation strategy's proposed using value stream mapping. The future VSM shows the production processes with the effect from energy saving solutions and applied intermediate storages as an energy storage in the production processes.

Fig. 17 describes the future value stream map with a plan to use the process named "Storage to boiler" for load scheduling like previously described and to implement the conservation strategy. It is possible to reduce losses behind the process of the woodchip conveyor from the main storage to the boiler stock. As was shown in Table XV, savings from the static demand side management are possible. Considering the implementation, the only economically feasible solution for energy saving is to reduce the losses behind the consumer unit. The initial variable consumption (IVC) in the process is 0.96 kWh/m^3. By increasing energy efficiency in the process 0.04 kWh/m^3, variable relative energy reduction (VRR) is 4.2%. So, the future variable energy consumption (FVC) is 0.92 kWh per 1m^3 of woodchips. Conveyors are working during the heating period, which is about seven months. The conveyor process of 1 m^3 of woodchips within 1.2 min called the cycle time is given in Fig. 17 as (Cycle. t.). The conveyor fast cycle time compared with the boiler results in the conveyor annual work hours of about 756 and annual variable energy consumption reduction (AVR) is 1524 kWh.

Fig. 17 shows the constant consumption in the process as well, i.e. the consumption which is independent of the processed m^3 of woodchips. This consumption results from lighting. Initial constant energy consumption (IFC) is 2.2 kW.

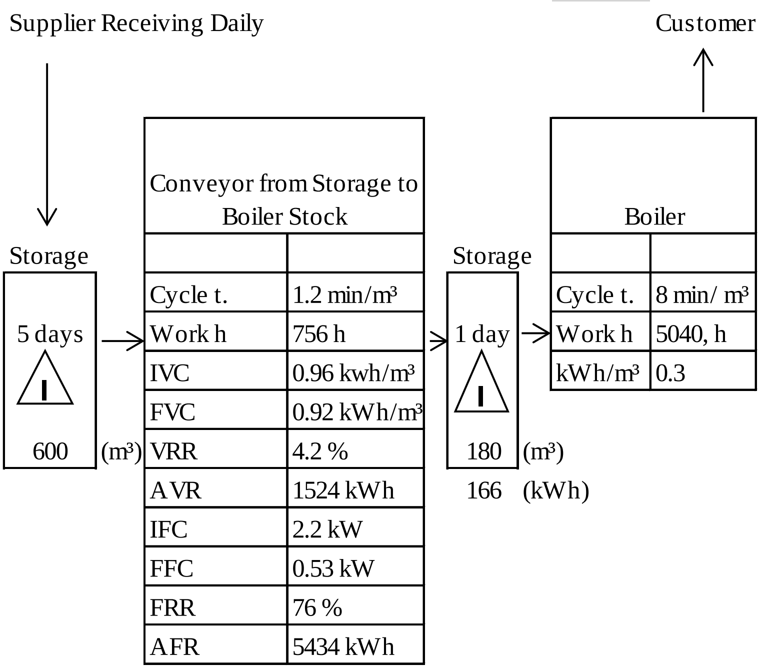

Fig. 17 Example of future VSM

It is proposed to use more efficient lighting; estimated future constant energy consumption (FFC) would be 0.53 kW, which constitutes a decrease of constant relative energy consumption (FRR) of 76%. The total of dark hours in the heating period is 3254 h, which is calculated based on the sunrise and sunset times in the conveyor location. Annual constant energy consumption reduction (AFR) is equal to 5434 kWh.

From the value stream map, we can read out also possible future state of load scheduling possibilities. In 5.2 load scheduling was described as the process is in the current state. From Fig. 11 we can see that in the future state, there are some implementations of static demand side management initiatives for load conservation. The value stream map shows that by processing one cubic meter of woodchips in the future state map, 0.92 kWh of electrical energy is consumed. Load scheduling possibilities have not changed and remain the same as described in section 5.2. Buffer time in process is still 23 hours and the boiler plant is connected to a grid at low voltage line, HPPP is still 83.4 euros per MWh and LPPP is 55.2 euros per MWh, potential saving from load scheduling is 33.8%.

As stored energy in the process is after static demand side management initiatives 0.166 MWh, by multiplying that with HPPP, the cost for the company will be 13.84 euros per day and saving from LS will be 4.68 euros per day.

In the proposed improved VSM method for the demand side management, energy cost saving tool was combined with existing production planning methodology. It is a developed visual tool, which includes load conservation and shifting in one methodology. Table XVI compares the proposed solution with other alternatives from three aspects: consideration of the load scheduling strategy; taking into account load the conservation strategy and availability of visualization description in order to show the implementation of load scheduling or conservation strategy.

Table XVI Comparison of the methods

Methodology description	Involves load scheduling	Involves load conservation	Visual
Proposed VSM	Yes	Yes	Yes
Alternative 1 “Real Time Control”	Yes	No	No
Alternative 2 “Quantitive Analysis”	Yes	No	No
Alternative 3 “Audit Plan”	No	Yes	Yes

Alternative 1 “Real Time Control” described in [23] proposes a solution for implementing load shaping strategy based on the real-time control of the processes by means of programmable logic controllers.

Alternative 2 “Quantitative Analysis” described in [61] focuses on the automotive industry and considers load scheduling together with the estimation of the whole process and its bottlenecks and intermediate storage buffers through continuous flow models.

Alternative 3 “Audit Plan” in [62] describes energy audit plan and energy conservation strategy execution. Also, it provides measurement of the conservation effect and possible visualization forms for showing the effect from conservation.

The benefit of the proposed method is that it is integrated with the already existing methodology used in industry for other purposes. The result is that quite significant part of the work can be done without necessity to focus on cost savings of energy, but other matters in the production value chain. Also, the method combines the analyses of possibilities for energy conservation and load scheduling. It means that dynamic and static energy cost saving analyses are combined. Finally, the information can be given in a standard visual of VSM, which makes it possible for the decision makers to understand the possibilities and benefits of the energy cost savings. Also, the proposed methodology can be adapted for the analyses of different kinds of resources in industry. Similar to the procedures described in this research, analyses of waste water, heat or steam consumption can be made. In the future work, such adaptions can be used to make the methodology applicable to all the resources in the production process. That kind of adaptations provide for efficiency and for resource audits throughout the industrial process that are required by the EU directive 2012/27/EU. [2]

6 Conclusion, Recommendations and Future Work

Current thesis has analyzed a practical approach to demand side management in the industry sector. The approach provides a valuable practical method to be adopted in the industry sector. The thesis research has addressed four different aspects:

1. Analyses of the boundaries of demand side management including calculations of the economic effect of demand response as a part of dynamic demand side management;
2. The methodology based on existing industrial management system for the demand response purposes;
3. The methodology elaborated for the static demand side management purposes;
4. Finally, the enhanced methodology was tested in a real-life test.

First, practical benefits of demand response with current boundaries were studied. Possible effect on the industry with considerations of boundaries in Estonia was analyzed, with the focus on the effect of demand response when consumption can be shifted in time. The analyses were based on the price difference in the electricity stock market in Estonia. If the loads are shifted from high price period to low price period, then load scheduling as a tool in demand response enables a cost reduction of 31% in our example. Current restriction boundaries are expanded by the novel approach to balance renewable energy unpredictable loads, such as a wind park by demand response. The proposed approach is different from traditional solutions as the aim is to reduce the cost of the balancing energy purchases by the renewable energy producer. Proposed approach requires direct cooperation with demand response provider and renewable energy producer. Direct cooperation is described as demand response provider and renewable energy producer should plan the energy production and consumption together and demand response provider needs to act almost instantly if it appears that forecasted production of wind parks differs from the real production. Possible benefits of such solution are described. Demand response provider can reduce the profit decline of wind parks. Profit decline on the Estonian example can be from 3.05 to 12.58 euros per MWh. In the thesis research, three wind parks were examined. About 30 to 44% of the profit decline can be reduced with demand response capacity equal to average wind park forecast imbalance. The restriction is that demand response provider must control its consumption two ways, i.e., to increase or decrease energy demand, as a forecast can be lower or higher than the real energy production.

The main purpose of the thesis research is to propose a novel methodology for the demand side management. The proposed methodology is based on the existing value stream mapping methodology, which was elaborated for adoption for demand side management purposes. Novel approach is divided to two categories: static and dynamic demand side management. Dynamic part is the active consumer behavior towards energy market such as, for instance, load scheduling, also called as demand response. Both static and dynamic demand side management were covered with the novel methodology. The bases of the methodology, as mentioned is the value stream mapping, are known from lean philosophy. Thus, the methodology uses the approach already known and used in the industry sector; as a result, it is more understandable and less worktime consuming. Many of the industries following lean philosophy have already value stream mapping, which makes it is easier to adopt demand side management in this case. Value stream mapping is extended with necessary data for demand side management. For example, data containing process energy consumption and possible consumption in future resulting from energy efficiency programs have been implemented. The novel methodology provides demand response possibilities, as value stream mapping contains processes and intermediate stocks with necessary data of process speed. This information enables load scheduling possibilities in the industrial process and redesign process scheduling based on the data provided by the value stream mapping and process energy intensity. In principle, process intermediate stocks will be used as a kind of energy storage.

The novel methodology was developed further to adopt also static demand side management initiatives. Static demand side management is mainly achieved by increasing the efficiency of the energy consumption. Development of the methodology is process based by outlining both the efficiency that is process dependent and independent. Process independent energy consumption and its efficiency are derived from the consumer units that support the process, but is unaffected by the process output. In other words, fixed consumption is related to the process output. For instance, this could be security lighting of the production facility. Process dependent consumption varies together with the process output and mainly consumer units are used for manufacturing. The static part of the novel methodology takes consumer unit as a main cornerstone to analyze energy efficiency. It addresses the energy efficiency in three aspects:

- efficiency before the consumer units;
- efficiency in consumer units;
- efficiency behind the consumer units.

Efficiency before the consumer unit analyzes the losses of energy in the distribution network that supplies energy for the consumer unit, starting from the commercial measuring point. This mainly includes losses in electrical lines and transformers. Efficiency in the consumer unit consists of the analyses of the consumer units themselves: mainly, their technological level by finding an answer to the question if there is a more efficient technology available. Also, it proposes to look at the control functions of the consumer unit, such as what the frequency of work cycles is and if it is reasonable to use variable speed drives. The final part of the static analyses side is the efficiency behind the consumer unit that proposes to analyze losses of the systems which are run or energized by the consumer units, for instance, the pneumatical or mechanical systems. The results of the static part of the methodology are also gathered into the value stream map, to provide an overall picture of the demand side management possibilities.

The novel approach test is also explained. Analysis of the experimental load scheduling is based on the district heating company in Estonia. It was found that the proposed methodology is usable as a simple tool to achieve cost savings with DR. The methodology proposed can be the first step for industry when implementing DR because of its simplicity. Also, in some cases, minor costs, reduced time and lower complexity can be achieved.

The final part of the study compares the proposed method with three alternative ways either for load scheduling or energy conservation methodology. The results of the comparison show that the proposed methodology is unique compared to

the alternatives, combining three aspects in one methodology: load scheduling, energy conservation and visual description.
The thesis research has proved that the improved value stream mapping methodology which takes into account also possibilities of dynamic and static demand side management increases the flexibility of the classical value stream mapping methodology; it is possible to achieve cost saving in the industrial process with dynamic and static demand side management. Our example showed that one process demand response provided 33.8% savings and static demand side management provided 4.6% of the production output dependent energy savings and energy savings of 76% independent of production output savings. It should be emphasized that this 76% is derived from savings in lighting by adopting modern technology.

6.1 Recommendations for policymakers

Global trends that mainly influence industry are an aging population, changes in the knowledge needed, increasing need for tailor made solutions and increasing need of industrial products in cities. In the EU context, the focus is on the regulations that support and effectively use EU economic alliance to overcome the tendency of falling behind the industrial and economic development of USA and China.

Policymaking practical outcome in Estonia and in other EU member states is the resource audits and investment support to resource usage efficiency including energy. For more effective outcome, more supportive tools are required for usage by the industrial personnel and resources similar to the proposed novel methodology. In order to have policymaking based on the influence of developed measure and possibly minimal administrative burden for the industry, tools that are quickly adoptable and understandable for the industrial sector should be provided.

To support the development of DSM as a part of energy and resource efficiency measure at a minimal administrative burden for the industrial consumers, the recommendations for the policymakers are as follows:

- to support continuously the measures for increase of energy and resource efficiency in the industry sector;
- to support with regulative measures the market development that considers the DSM effect on the energy systems and allows transmission of created value to the consumer level;
- to support with regulative measures the market development of aggregated demand response, as the different consumers alone cannot provide necessary effect on the energy system but DR in aggregated way can provide this;
- to support the development of flexible methodology for energy and resource efficiency evaluation (e.g. described in the thesis), taking into account all important resources like: water, heat, electricity, steam, land etc.

6.2 Future work

Future work should address adoption of the novel methodology for the whole resource audits in industry. It is possible to describe other resources used in industrial processes in a way similar to that described for demand side management possibilities. The thesis outlines main resources beside energy like water, primary energy and use of land. By adopting other resources into VSM it is possible to provide resource audits in the industry sector to achieve targets in resource efficiency. As described at the beginning of this work, analyses of energy and resource efficiency made so far only compute one of the issues: either energy or resource efficiency. It is generally assumed that increasing energy efficiency will lead to improved resource efficiency and vice versa, but combined analyses are still scarce. Further development of the current approach will enable provision of one methodology for all the important resources for the industry and overcome the issues related with resource efficiency.

In addition, studies should focus on the risk of rebound effect after energy efficiency increase. The behavior of decision makers in industry after implementation of DSM can influence the achieved effect with the improved VSM methodology. Continuous monitoring and development methodology should be developed so that demand side management initiatives would be a permanent part of the production and risk of the rebound effect would be minimized.

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Acknowledgements

Firstly, my deepest gratitude is due to my supervisor Dr. Argo Rosin who has guided me during my studies. I would like to express my gratitude to my former colleagues Innar Kaasik, Andres Alusalu for their contribution to provision of necessary access to facilities used for exemplifying purposes in this work. I would like to thank Dr. Imre Drovtar who guided me at the beginning of this work and in our common research papers.
Providing a time resource for my research and paper and thesis writing has been highly challenging for me and for my family. I would like to thank my family: my wife Annika Melsas, my son Rainer Melsas and my daughter Anete Melsas for their understanding and support during the whole period of this thesis research.
Tallinn University of Technology is gratefully acknowledged for the financial support.

Thank you!
Raivo Melsas

Lühikokkuvõte

Väärtusahela metoodika uurimine ja arendamine tarbimise juhtimise võimaluste hindamiseks tööstussektoris.

Doktoritöö käigus on väljatöötatud täiustatud väärtusahela kaardistamise metoodika, et hinnata elektrienergia tarbimise juhtimise sh energiatõhususe tõstmise ja tarbimise nihutamise võimalusi kogu tootmisprotsessis. Teema on aktuaalne seoses taastuvate energiaallikate järjest laialdasema kasutuselevõtuga, mis põhjustavad halvasti planeeritavaid või prognoositavaid elektrienergia tootmise mahtusid. .

Täiustatud väärtusahela metoodika muudab energia- ja ressursitõhususe hindamise paindlikumaks ja ajaliselt tõhusamaks, sest võimaldab tootmist analüüsida kahest vastuolulisest eesmärgist lähtuvalt. Nimelt väärtusahela algne eesmärk vähendada tootmisprotsessidele kuluvat aega ja vähendada ladusid on vastandlik tarbimisjuhtimise meetodile kus tootmist planeeritakse vastavalt elektrisüsteemi vajadustele.

Töö esimene ja teine peatükk annavad ülevaate taustast, tarbimise juhtimise varasematest uuringutest ja potentsiaalist erinevates tööstusharudes. Töö teine peatükk keskendub peamiselt tarbimise juhtimise klassifitseerimisele ning selgitab dünaamilise ja staatilise tarbimise juhtimise erinevust. Samuti on kirjeldatud uusi võimalusi dünaamiliseks tarbimise juhtimiseks, mis tuleneb avatud elektriturust ja selle kõikuvast tunnihinnast. Lisaks kirjeldatakse tootmisjuhtimise metoodikat ja võimalikke vastuolusid tootmise juhtimise eesmärkide ning tarbimise juhtimise vahel.

Kolmanda peatükis on analüüsitud taastuvenergia tootmisega seotud tarbimise juhtimise eeliseid, et tasakaalustada elektrisüsteemi ja vähendada taastuvate energiaallikatest tulenevat tootmismahtude prognoosi vigu.

Neljandas peatükis kirjeldatakse uut ehk täiustatud väärtusahela kaardistamise metoodikat tööstussektori tarbimise juhtimise võimaluste hindamiseks. Uus metoodika põhineb väärtusvoogude kaardistamisel, arvestades koormuse ajalise nihutamise võimalusi kogu tootmisprotsessis. Edasiarendatud metoodika seisneb vaheladude kasutamisel tarbimise juhtimise eesmärgil .

Viiendas peatükis katsetatakse välja töötatud metoodikat reaalsel objektil ning kuuendas peatükis on esitatud kokkuvõte ja soovitused poliitika kujundajatele.

Tööst on kasu tööstuse tootmise planeerimisega ja tarbimise juhtimisega tegelevatele tippspetsialistidele. Arendatud metoodika pakub tööstusele sobiva lähenemisviisi tarbimise juhtimise hindamiseks sõltumata selle tüübist või geograafilisest asukohast.

Abstract

Research and Development of Improved Value Stream Mapping Methodology for Evaluation of Demand Side Management Possibilities in the Industry Sector

The thesis presents an improved value stream mapping methodology to evaluate demand side management (DSM) possibilities of the whole production process, including energy saving and shifting. The current relevance of the thesis is related to increasing unpredictable electrical energy production from renewable energy sources and practical DSM possibilities to provide power grid balancing possibilities. Proposed methodology improves flexibility and efficiency of energy and resource efficiency analyses in the industry sector.

Chapters 1 and 2 cover background information, previous research and potential of the DSM. New possibilities for demand response, as a part of dynamic demand side management, are explained that are derived from open electricity market and its fluctuating hourly price. Also, the study addresses the methodology used in production management, and possible conflict between production management goals for reducing production stock levels and improve demand side management possibilities.

Chapter 3 analyzes the benefits of demand side management for the renewable energy production in order to balance the power system and reduce forecast errors from renewable power plants (i.e. wind parks). The outcome is described through direct cooperation of demand response provider and wind parks. Real life cost efficiency increase from demand side management was calculated for use in balancing wind energy forecast errors.

Chapter 4 introduces the novel methodology for the evaluation of demand side management possibilities in the industrial sector. Value stream mapping as a base tool was elaborated in order to take into account the whole process for finding load shifting possibilities. Value stream mapping is a well-known tool in lean production and known for production oriented persons. Proposed method is utilizing intermediate stock as a kind of energy storage for demand response purposes. The efficiency increase possibilities were added to value stream mapping to achieve comprehensive methodology for demand side management.

Chapter 5 presents the test for the proposed methodology on a real life example. In order to provide practical proof of the improved value stream mapping, a methodology for the evaluation of demand side management in the heat production industry is given. The example consists of load scheduling and energy conservation evaluation.

Finally, Chapter 6 presents the conclusion and recommendations for policy- makers.

The developed methodology could be helpful for the industry operational excellence program facilitators, demand response developers, and demand side aggregators as well. The developed methodology is applicable in industry despite its type or geographical location.

Appendixes

PAPER I R. Melsas, A. Rosin and I. Drovtar, "Wind park cost efficiency increase through direct cooperation with demand side response provider," 2016 57th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Riga, 2016, pp. 1-5. doi: 10.1109/RTUCON.2016.7763119

Wind Park Cost Efficiency Increase through Direct Cooperation with Demand Side Response Provider

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Abstract—**Demand side response enables cost optimization for energy systems and consumers. By tradition, the target of the demand side response is to shift the loads from high price or peak-load periods to low price or low consumption periods. The economic effect is derived from reduced energy purchasing costs. This paper focuses on the possibility to provide demand side response for a wind park through direct cooperation by means of reduced production forecast errors. These errors are costly, as in open electricity market, overproduction is usually sold at a lower price and in underproduction it is required to purchase balancing energy from an electricity market. Forecasting errors always occur, as a forecast consists of wind speed predictions and does not take into account unexpected stops. Demand side response will reduce the imbalance between forecasted and actual production in wind parks. Direct cooperation between a response provider and a wind park is complex, as the forecast errors will define the need for the demand side response. For that reason, it is required to analyze wind park forecast errors in order to define the requirements for the demand side response capacity and an energy storage size. On the other hand, the solution proposed in this paper has benefits, as a demand side response provider does not need to participate in energy market. From that fact electricity market requirements are not applicable, as an example there is no need to have certain capacity available to participate in market.**

Keywords— wind farms, forecasting, demand response, energy storage

I. INTRODUCTION

Demand side response (DSR) provides opportunities for the renewable energy sector to balance unpredictable production. The share of renewable energy in total electricity production is rising continuously in the world. Renewable energy (RE) producer has a need for DSR. The reason is that in an open energy market, RE producer has to plan energy production one day ahead. Forecasts have to be made for short periods, e.g. in Nord Pool Stock an hourly forecast is required. In case the quantity of produced energy is less than the forecast, the RE producer must buy additional energy from a balancing market. If the production is higher than the forecast, RE producer will sell produced energy to the balancing market, usually at a lower price. There will be a decline of profit from the difference between the forecasted and real production. We shall call, that difference as forecast imbalance (FI). Below in (1) is shown the calculation of the energy of FI (E_{FI}). That is difference between forecasted energy production (E_F) and real energy production (E_R).

$$E_{FI} = E_F - E_R \tag{1}$$

Focus in this paper is on the possibility to reduce the decline in profit from FI by use of DSR. Profit decline will appear at a particular hour when E_R is different from E_F, which indicates that there is a need for fast and direct co-operation between the RE producer and the DSR provider. Under direct co-operation, DSR must have fast reaction time for balancing RE production. DSR provider will benefit from the service and can utilize cheaper energy, which is the result of FI. A good example for the RE producer is a wind park that will always have FI because the wind is not well predictable. DSR with fast reaction time can be provided, for example, by electric boilers with heat storage or industrial processes that can be shifted in time. In this paper, we will provide a solution for wind parks to have DSR in direct cooperation for reduction of costs related to production forecasting errors. Section II analyzes the FI of the wind parks, which is required to estimate the DSR potential. Section III reviews DSR solutions and energy storage requirements. In section IV, economic effect for DSR is calculated under balancing wind parks FI.

II. ANALYSES OF WIND PARKS FORECAST IMBALANCE

Many articles address accurate forecasts of wind park output power. Reference [1], for example, presents a model for short term wind speed predictions with artificial neural networks. An approach for short term wind power forecasting using a hybrid intelligent system is proposed in [2], [3] on the other hand presents more generic frame work for wind power forecasting.

We have studied three different wind parks (located different regions in Estonia). Wind park production is forecasted in two steps. First, the availability of each turbine is taken into account. Wind turbine availability for the next day is planned a day ahead in order to provide on time production plan to the electricity spot market. Availability is forecasted on hourly basis. Second, the wind park availability plan is given for production estimation. Production estimation takes into account turbine stop times, wind meteorological forecast in the wind park location and turbine production curves. Turbine production estimation also considers historical data for error correction. Nevertheless, the energy production

This research was supported by the Estonian Centre of Excellence in Zero Energy and Resource Efficient Smart Buildings and Districts, ZEBE, grant 2014-2020.4.01.15-0016 funded by the European Regional Development Fund..

978-1-5090-3731-5/16/$31.00 ©2016 European Union

forecasts are not 100% accurate. Table I present the share of E_{FI}. Wind parks are named WP-A, WP-B and WP-C and in analyses the period considered was 1 October 2014 until 30 September 2015. As Table I shows, all three wind parks have a significant share of energy sold or bought from a balancing market.

TABLE I. SHARE OF WIND PARKS FORECAST IMBALANCE FROM REAL PRODUCTION

Wind park	E_{FI} from total E_R, %	
	$E_F<E_R$	$E_F>E_R$
WP-A	16	17
WP-B	13	14
WP-C	10	23

To describe the accuracy of the forecast, a normalized Mean Absolute Percentage Error (*nMAPE*) given in [4] is presented in (2):

$$nMAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{P_a - P_f}{P_{inst}}\right| \cdot 100\% \,, \quad (2)$$

where P_a is actual wind park output power; P_f is forecasted wind park power; P_{inst} is installed capacity of the observed wind park; and n is number of hours in period.

nMAPE for total Estonian installed wind power capacity in [4] is given as 6.07% for the period 01.06.2012 to 30.05.2013. In our case, the corresponding numbers for three wind parks are 8.02% for WP-A; 7.02% for WP-B and 6.74% for WP-C. These higher numbers can be considered normal as a cumulative error is smaller than in each individual wind park. For example calculating *nMAPE* for three wind parks cumulatively, we obtain 5.15%. With DSR, FI can be supported even better than just cumulating all forecasts together. In that case, DSR provider will forecast production as well and can reduce or increase its production according to RE producer FI in equal opposite amounts. DSR providers are also responsible for planning their load accurately, i.e. FI of DSR provider equals with 0 in case DSR services is not needed. Taking into account (1), the DSR can balance FI of the RE producer with an opposite load imbalance, as shown in (3):

$$E_{DSR} = E_{RE} \cdot (-1) \,, \quad (3)$$

where E_{DSR} is DSR provider FI and E_{RE} is FI of the RE producer. In case RE producer and DSR service provider have composed a common balancing region, then from the balance management point of view, total FI is equal to the sum of the FI of the RE producer and DSR service provider FI, as shown in (4):

$$E_{Tot} = E_{RE} + E_{DSR} \,, \quad (4)$$

where E_{Tot} is the energy of total FI.

Table I shows the share of the produced energy that could be balanced by DSR. To have 100% DSR for that energy, DSR capacity must be equal to the nominal power of the wind park. From a practical point of view the maximum needed capacity of FI from wind parks is not reasonable, as the maximum is seldom used. Financial calculations in each individual case must be made to find an optimal DSR capacity. To find the optimal capacity, the annual utilization of the DSR in an amount agreed has to be found. It is reasonable to examine DSR capacity utilization on the graph, which shows duration in hours when E_{FI} is to be balanced in the nominal DSR capacity. This is shown in Fig. 1 for three wind parks.

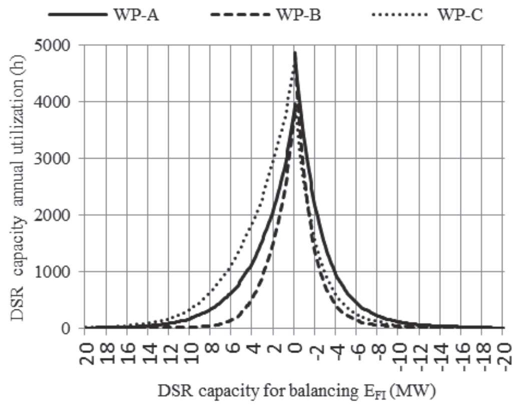

Fig. 1. Annual utilization of DSR capacity for three wind parks

In our analyses, for having good utilization, we use DSR capacity equal to an hourly average FI from wind parks. Table II shows an average FI from the three wind parks.

TABLE II. AVERAGE FORECAST IMBALANCE FROM WIND PARKS

Wind park	Average E_{FI}, MWh	
	$E_F<E_R$	$E_F>E_R$
WP-A	-1.36	1.47
WP-B	-0.86	0.91
WP-C	-0.94	2.20

To provide DSR for full FI, the capacity required is more than 10 times higher than if DSR is provided for the average FI. Also, based on Fig. 1, it can be stated that almost every hour, a need of DSR for the wind parks is present. Table III shows the time period (t_{FI}) in a year when FI can be balanced with the DSR nominal capacity which is equal to average FI of wind parks. Utilization time is one of the important parameters in calculation of economic effect of DSR.

TABLE III. DUARATION OF AVERAGE FORECAST IMBALANCE

Wind park	Duration t_{FI} of average E_{FI}, h	
	$E_F<E_R$	$E_F>E_R$
WP-A	2732	2531
WP-B	2686	2564
WP-C	2431	2906

To estimate the effect of the proposed DSR capacity, the annual E_{RE} that can be balanced by DSR (E_{CFI}) is found using (9) and share from total FI (E_{share}) is found using (10): .

If $E_F > E_R$, then:

$$\text{if} \quad E_{FI,i} < E_{PFI} \text{ then } E_{FI} = \sum_{i=1}^{n} E_{FI,i} \,, \tag{5}$$

$$\text{if } E_{FI,i} \geq E_{PFI} \text{ then } E_{FIn} = \sum_{i=1}^{n} E_{PFI,i} \tag{6}$$

if $E_F < E_R$, then:

$$\text{if} \quad E_{FI,i} > E_{NFI} \text{ then } E_{FI} = \sum_{i=1}^{n} E_{FI,i} \,, \tag{7}$$

$$\text{if } E_{FI,i} \leq E_{NFI} \text{ then } E_{FIn} = \sum_{i=1}^{n} E_{NFI,i} \,, \tag{8}$$

$$E_{CFI} = E_{FI} + E_{FIn} \,, \tag{9}$$

$$E_{share} = \frac{E_{CFI}}{\sum_{i=1}^{n} E_{FI,i}} \,, \tag{10}$$

where i is an hour in the overall period, defined by n; E_{PFI} is maximum positive balanced energy by DSR; E_{NFI} is minimum negative balanced energy by DSR and E_{FIn} is sum of applied E_{PFI} or E_{NFI}, as given in (6) and (8), respectively. E_{FI} is calculated as a sum of energy of FI in the particular hour i, calculated with (5) and (7) respectively In our analyses, E_{NFI} equals an average negative FI and E_{PFI} equals an average positive FI by a wind park. The results are given in Table IV.

TABLE IV. BALANCING CAPACITY AND PERCENT FROM TOTAL FI, IF THE DSR SIZE IS EQUAL TO AVERAGE WIND PARKS FI.

Wind park	Balancing capacity E_{CFI}, MWh		Share from total FI E_{share}, %	
	$E_F<E_R$	$E_F>E_R$	$E_F<E_R$	$E_F>E_R$
WP-A	-4976	4632	41.8	36.0
WP-B	-3148	2872	41.8	35.9
WP-C	-2952	8186	35.8	42.4

As can be seen from Table IV, DSR with nominal capacity equal to average FI can reduce approximately 36% to 42% of the total FI. With relatively small DSR capacity the share of FI reduced is quite high.

III. DSR POSSIBILITIES AND ENERGY STORAGE REQUIREMENTS

As was shown above, a significant amount of FI is present and a positive effect can be achieved when applying DSR to decrease it in wind parks. Several DSR systems, such as hydro power stations, described in [5] can be applied. Also, more complex systems have been analyzed in [6] where thermal power, hydro power and flow batteries are used for hybrid power balance control. In [7] it has even been proposed to have a small scale hydro power station for storing energy during low price periods and releasing it at high price periods. According to [8], the back-to-back approach does not often take into account power system operation in energy market and its economic efficiency. Back-to-back approach is described as a system where wind power is used to fill up the storage during high wind periods, and the storage energy is used when there is no wind. In the proposed DSR with direct cooperation between the RE producer and the DSR provider, some special aspects must be considered and applied. These include a need to provide DSR within the same hour when FI is appearing, so that DSR will react to FI errors almost online. DSR is required to have an accurate load forecast, participation in day-ahead energy market and efficiency in energy conversion. For those particular restrictions, a suitable DSR provider can be an electric boiler with heat storage. This system in an aggregated form is described in [9], controllable electric water heating and storage systems cooperation under control for DSR is presented. For effective DSR, proposed solution requires energy storage as well. Next we will calculate general requirements for energy storage and heat storage.

A. Energy storage and heat storage requiremets for DSR

In our approach of DSR implementation, energy storage in different forms is required. Further, we will analyze energy storages required to correct FI of wind parks. Energy storage capacity required depends on the time necessary to cover the FI. The participants in Nord Pool Stock have to be provided a day-ahead market production plan at 12:00 pm for the next day [10]. Thus, every 24 hours, a DSR provider can adjust its energy load plan according to energy storage fulfillment. This, however, is not sufficient, as it fails to take into account the period of time when the next production plan will come into force. If the plan is made at 12:00 pm, the period to the end of the day must also be taken into account. This means that the size of energy storage must be large enough to balance FI at least for 36 hours. DSR provider should have energy storage available for the end of the day when planning is made for 12 hours and 24 hours in the new planned period. With a forecast change, it is possible to plan to empty or to fulfill heat storage in order to keep an optimal storage amount. If the longest period to store the energy by DSR into energy storage is 36 hours, the energy required to store (E_s) in storage can be found by (11) and (12).

$$E_S = \frac{P_{DSR} \cdot t}{\eta} \,, \tag{11}$$

and

$$P_{DSR} = FI_a \cdot 2 \tag{12}$$

where P_{DSR} is nominal power for DSR; FI_a is forecast imbalance which is agreed to be balanced by DSR; t is time period required by FI; and η is efficiency of the energy storage. FI_a must be multiplied with 2 because of a need to have storage on both sides for surplus energy and for lack of energy. In case P_{DSR} equals FI_a, DSR provider can only balance the energy when the RE producer E_F is more than E_R; in that case, DSR will stop using energy equal to FI_a. In case E_F is less than E_R, DSR is required to increase its energy usage. To cover this case as well, it is required to increase the load of DSR equal to FI_a (in maximum). As FI requires an increasing DSR load, it is optimal to keep storage half full so that increased load can be stored.

One example of energy storage can be electric boilers in aggregated form. The required heat storage capacity is given in Table V; boiler efficiency is considered to be 85%, 5% loss will come from the heating unit (e.g., heating electrode) and 10% of loss is considered as loss from heat storage during 36 hours. For FI_a, maximum wind parks E_{FI} absolute values are taken from Table II.

Based on the energy storage requirement shown in Table V, we can calculate the storage volume by (13) if water heat storage is used:

$$V_S = \frac{Q_S}{\rho \cdot c_p \cdot (T_{a2} - T_{a1})}, \qquad (13)$$

where V_S is volume of the heat storage in m^3; ρ is water density; c_p is specific heat at constant pressure; T_{a2} is required maximum temperature; and T_{A2} is required minimum temperature.

Heat storage size required for FI of the wind parks is presented in Table V as well. In the calculation, the following parameters are used: ρ=1000 kg/m^3, c_p=4180 J/(kg·K), T_{a2}=60 ^{0}C and T_{a1}=7 ^{0}C. Temperatures are chosen as typical parameters for electric boilers for tap water heating.

TABLE V. HEAT STORAGE CAPACITY REQUIRED FOR FI OF THE WIND PARKS

Wind park	nominal power for DSR P_{DSR}, MW	Heat storage capacity E_s, MWh	Volume of the heat storage V_S, m^3
WP-A	2.94	125	2014
WP-B	1.82	77	1247
WP-C	4.40	186	3015

As described previously, electric boilers need heat storage with sufficient capacity. A calculation based on the average FI from wind parks was made to find heat storage capacity.

IV. ECONOMIC EFFECT OF WIND PARKS FROM DSR

This section focuses on the economic evaluations. Calculations made are based on the three wind parks and Estonian electricity market, which is part of Nord Pool Stock. Under direct cooperation with RE producer, DSR can have a positive effect only if it reduces costs for the RE producer. Positive effect results from the situation where the RE producer suffers under the decline of profit from the energy that is inappropriately planned and forecasted to the market. Next, we will look at the difference of the energy prices between planned, mean day-ahead prices (DAP) and unplanned mean balancing market price (BMP). In order to find out economic effect, it is required to find out price differences between BMP and DAP. It must be pointed out that BMP is not always more expensive than DAP and a difference for the producer depends on whether one buys or sells energy with BMP. In case of selling to a balancing market, BMP was more expensive than DAP in 3017 hours, i.e. 34% of the time. In case of purchase from a balancing market, BMP was more expensive than DAP in 4581 hours, i.e. 52% of the time. In case BMP is cheaper than DAP and RE producer has to buy from a balancing market, due to FI, the RE producer will have an increase of profit instead of decline. Also, if BMP is higher than DAP and the RE producer has to sell some of the energy with BMP due to underestimation of the energy production, RE producer can gain an increase of profit. Balancing market trade is managed by transmission service provider (TSO) and is separate from a day-ahead market. RE producer without manageable electricity production must use service from a balancing market and is unaware of whether it is more beneficial to forecast more or less. As a result of our study of three wind parks, we found out that they have a decline of profit. In the calculation, a possible profit increase was also taken into account, however in total, wind parks still lose profit from FI.

RE producer profit decline c_{re} was calculated as shows (14).

$$\begin{aligned} c_{RE} = & (\sum_{i=1}^{n}(BMP_{S,i} - DAP_i)\cdot E_{FI,i}; E_{F,i} > E_{R,i}) + \\ & + (\sum_{i=1}^{n}(BMP_{P,i} - DAP_i)\cdot E_{FI,i}\cdot(-1); E_{F,i} < E_{R,i}) \end{aligned}, \qquad (14)$$

where $BMP_{P,i}$ is energy price under a need to purchase from a balancing market; $BMP_{S,i}$ is energy price under a need to sell to a balancing market; i is particular hour when a transaction is made; and n is the number of hours in the analyzed period. DSR can reduce the decline of profit; however, an effect from it must be found hour by hour and after BMP is known. To show the economic effect that DSR can have, for win parks FI, we have calculated an average profit decline per one MWh of FI, shown in Table VI.

TABLE VI. AVERAGE PROFIT DECLINE C_{RE} FROM WIND PARKS FI PER MWH

Wind park	Average profit decline C_{RE}, EUR/MWh	
	E_F<E_R	E_F>E_R
WP-A	4.39	4.12
WP-B	6.12	6.19
WP-C	12.58	3.05

The average FI from wind parks was calculated in section II. Next, the decrease of profit decline through DSR with the capacity equal to average FI of wind parks is evaluated. DSR capacities in wind parks are as follows: WP-A 1.47 MW, WP-B 0.91 MW, and WP-C 2.2 MW. Fig. 2 shows the result of the economic effect of DSR implemented in the given capacity.

As was shown in Fig. 2, economic effect is reachable and DSR service provider can decrease profit decline from FI of the wind parks about 30 to 44%. By decreasing profit decline some of the economic effect must be transferred to DSR provider as well. AS the result economic efficiency of DSR provider will increase. By proposed solution there will be profitable effect for the RE producers and DSR providers.

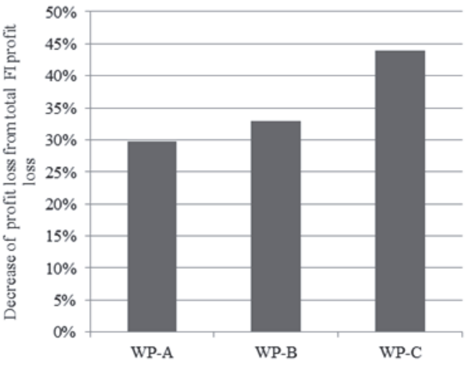

Fig. 2. Profit loss decline of wind parks through DSR.

V. Conclusion

This paper provides an approach to apply and benefit from DSR. We propose to reduce FI of the RE producer such as a wind park by DSR. The proposed solution is different from traditional DSR solutions where the aim is to reduce the cost of energy purchases. It requires direct cooperation with a DSR provider and a wind park. Direct cooperation means that a DSR provider and a wind park are planning the energy production and consumption together and action by the DSR provider is needed if the production forecasted by a wind park differs from the real production. Some benefits for the DSR provider can be derived from direct cooperation, as the DSR provider has no need to participate in an energy balancing market directly and those requirements are inapplicable. For example requirement for the minimum capacity to participate in balancing market is not applicable.

DSR provider can reduce wind park profit decline from FI. Profit decline can constitute 3.05 to 12.58 euros per MWh in the three examples provided. About 30 to 44% of the profit decline from the total FI profit decline can be reduced with the DSR capacity equal to average wind park FI. The DSR provider must control its consumption in two ways, i.e. to increase or decrease energy demand, as forecast of the wind park can be less or more from the real energy production. Two-way consumption control requires that the DSR provider have double DSR capacity compared with the wind park FI, which is agreed to be balanced. As a result, we can state that the solution provided shows a positive economic effect of DSR for the wind parks and makes it possible to use DSR in a small scale, as the wind parks are in many different sizes.

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PAPER II

R. Melsas, A. Rosin and I. Drovtar, "Value stream mapping for evaluation of load scheduling possibilities in a district heating plant," 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), Florence, 2016, pp. 1-6. doi: 10.1109/EEEIC.2016.7555696

Value Stream Mapping for Evaluation of Load Scheduling Possibilities in a District Heating Plant

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Abstract — **Demand side response enables cost optimization for energy systems and industrial consumers. In many countries, it is not widely used because of implementation complexity. One of the solutions for applying demand side response is industrial process scheduling according to the energy market needs. From the energy system point of view, process scheduling implies load scheduling. The aim of this paper is to provide a solution for load scheduling by implementing value stream mapping, which is a straightforward enough for production management. Decision makers in the industry should have a clear understanding about positive effect from load scheduling and its effect to production outcome and process availability. Value stream mapping is a well-known process optimization tool from lean production philosophy. The aim of value stream mapping is to shorten the lead time of industrial processes and to reduce the intermediate stock amounts. By complementing value stream map with process energy intensity and energy stored in intermediate stocks, we can promote load scheduling possibilities. Our methodology provides a tool that is understandable and traceable for industry-minded decision makers. Finally, we present a real life test example for the new methodology, which is based on the production process of a district heating plant.**

Keywords— demand response, energy storage, load management, load scheduling, value stream mapping

I. INTRODUCTION

Load scheduling (LS) as part of demand side response (DSR) must meet the needs of industry. One of the effects for the industry appears when load consumption is shifted from periods of high electricity price to those of low price. As a result, cost savings can be achieved by means of reduced consumer demand in high price periods. This requires better production planning, which is related to production management.

Previous DSR studies have resulted in the following: static Stackelberg game theory for voluntary load curtailment programs [1]; numerical calculation method for DSR when a battery energy storage system (BESS) is utilized [2]; solutions for DSR by means of automatic lighting [3]; DSR with micro-CHP systems [4]; an overview for DSR methods in high consumption industries and examples of market tools that support DSR [5]. In [6] an automated complex system for LS in industry is described, which takes into account stock restrictions, maintenance schedules, and crew management. All the necessary inputs are analyzed with a fuzzy/expert-based system combined with an optimization module. As a result, the system is able to identify whether and how much the industrial plant can participate in a DSR event. In [7] and [8] DSR is addressed as a part of the following main load shaping strategies:

a) conservation - energy saving is achieved through static methods;

b) load growth - energy consumption is increased when an energy system has surplus energy production;

c) valley filling - load is increased through the off-peak periods or keeping stable consumption;

d) peak clipping - energy consumption is decreased in peak periods;

e) load shifting - peak consumption is shifted from peak periods to non-peak periods;

f) seasonal load reduction - annual energy peaks are reduced.

LS is used mainly in "load shifting" strategy e; however, in some cases, "valley filling" strategy can be utilized as well. To use the LS, an industry must have the following one or several DSR options [8]: cooling equipment with cooling storage, heating equipment with heat storage, dual fuel systems that can operate either on electricity or on an alternative fuel, discretionary loads and process equipment that can be shifted during a short period or material handling equipment with storage possibilities (silos, stock, etc.). This paper focuses on the last option by looking at process as a whole in order to find LS solutions. In addition, it provides a method applicable in industry for outlining the possibilities with LS as a part of DSR by using value stream mapping (VSM). VSM is applicable in various ways. Originating from Toyota Production Systems [9], it was further elaborated and adjusted to find solutions for different problems in the production process. For example, VSM is used to solve quality problems [10]. This paper elaborates on VSM. Our proposal is to use it for indicating a possibility to shift an electrical load from a high price period to a low price period and utilize an intermediate stock for energy storage [11], [12], [13]. This paper will provide a straightforward solution for the industry in order to apply LS effectively and which is easily applicable.

This research was supported by the Estonian Centre of Excellence in Zero Energy and Resource Efficient Smart Buildings and Districts, ZEBE, grant 2014-2020.4.01.15-0016 funded by the European Regional Development Fund.

978-1-5090-2320-2/16/$31.00

II. Energy Price as a Driver for Load Shifting

LS can yield an economic effect under rational consideration. Cost reduction can be achieved by taking advantage of energy price fluctuations during a day. It is reasonable to have demand response implemented in countries where an electricity pool exists and hourly based spot prices are known for a short period ahead. As a result, industries can plan their production according to the spot price. Fig. 1 shows an average 24-hour electricity market spot price in Estonia in 2014 [14]. As can be seen, electricity spot price is typically higher from 07:00 A.M. to 8:00 P.M. In general, there is at least 10-euro price difference during a day and a night. Considering the price peak and dip approximately 20-euro difference per MWh exists during a day. On average, price difference during a day is 15-euro MWh.

However the consideration above includes only electricity price; in addition, there are some fluctuations in grid service price as well. From 12:00 A.M. to 8:00 A.M. (11:00 P.M. to 7:00 A.M. in winter time), the grid service price is lower. This period is not overlapping 100% with a low spot price period. We will call this period (12:00 A.M. to 8:00 A.M.) as the Low Price Period (LPP) and the other period during a day as the High Price Period (HPP). Grid tariffs depend on grid connection voltage level and connection capacity (amps). In the following, we will describe one example to examine the daily price difference for the industry in Estonia.

At substantial electricity consumption, an industry is usually connected into a middle voltage (MV) grid. In that case, Estonian grid service price is 14.5 euros per MWh from 8:00 A.M. to 24:00 A.M. and during LPP 8.3 euros per MWh [15]. For some customers, no time difference is applied; the price for grid services is constant in time- 12 euros per MWh. Fig. 1 shows both the grid price and the spot price fluctuations.

In 2014, an average electricity spot price for LPP was 29.5 euros per MWh and with grid price fluctuations it amounted to 37.8 euros per MWh, which we call as the Low Price Period Price (LPPP). In 2014, an average HPP spot price was 40.9 and together with grid tariff, the average number was 55.1 euros per MWh, which we call as the High Price Period Price (HPPP). For clarity, 55.1 is an average found on hourly bases, i.e. spot price + grid price.

Based on the data provided, we can calculate potential savings for industry under LS. Potential cost saving is 31%, which is calculated by (1):

$$CS = \frac{HPPP - LPPP}{HPPP}. \quad (1)$$

In general, it can be concluded that grid tariff fluctuation has an important role in LS in Estonia, as the average difference in the spot price between HPP and LPP was 11.4 euros per MWh and grid tariff will add extra for the difference between HPPP and LPPP, according to [15], tariff depends on the grid connection parameters.

The shape of the electricity spot price in Fig. 1 can be considered as a typical shape of the daily demand of electricity as well; a similar shape of demand can be found in various places, e.g., even in South Africa [16]. Thus, DSR has a positive impact to overall efficiency to energy systems, not only to an industry itself.

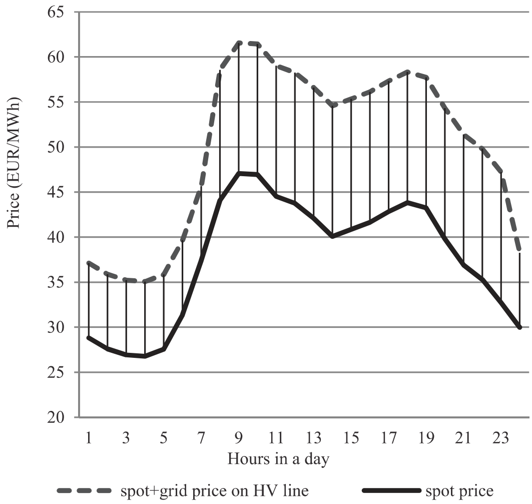

Fig. 1. Average Estonian 2014 electricity spot price during a day.

III. Improvement of Value Stream Mapping Methodology for Evaluation of Load Scheduling Possibilities

A. *Load Scheduling at Intermediate Storage Use in Production*

In the following, LS possibilities are examined for intermediate storage use as an energy saving unit, to enable shifting of energy intense production from HPP to LPP. In LS, it is important to understand energy intensive production units and their overall role in the production. Methods from lean philosophy [LP] can be used here. We propose to improve the value stream mapping (VSM) methodology with LS principles. Today LP is a leading production management philosophy. VSM is used to plan production as efficiently as reasonably possible. Energy intensity can be added in a process as additional information for a VSM, which will give a good overview about the possibilities in energy saving. Fig. 2 gives an overall picture of a typical VSM, elaborated with process energy intensity and amount of energy stored in the production intermediate storage.

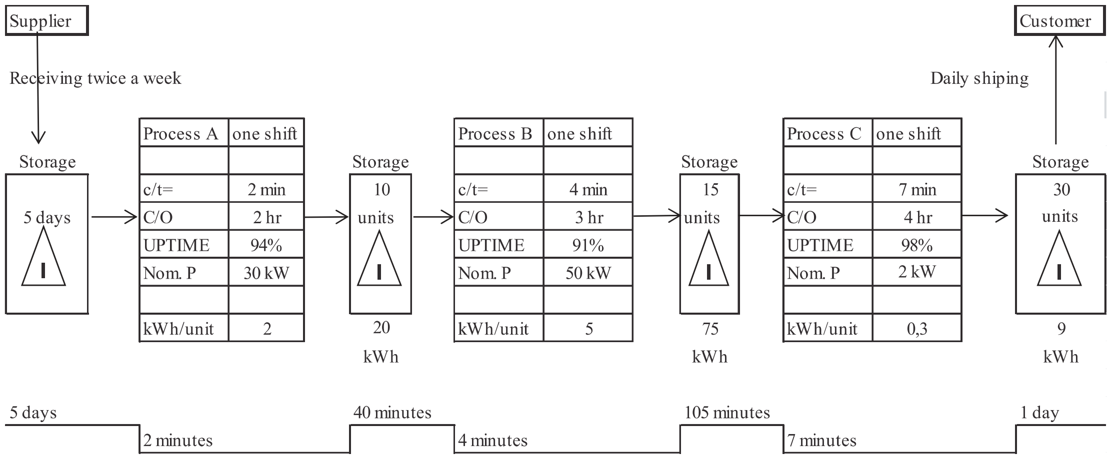

Fig. 2. VSM with energy consumption and storage overview.

As VSM gives an overview of the production planning and can additionally give information about energy intensity, the possibility of the LS should be studied in detail. From VSM, we will know if an energy intense process is at the same time a bottleneck in production. If it is not true, then the conclusion is that this process is not 100% utilized in time and LS can be implemented without increasing process capacity. Alternatively costs for increasing process capacity (CPC) need to be calculated.

Next, we focus on the storage. If production is shifted in time, storage volume can increase as compared to the state without LS utilized. Storage increase may need additional investments, which should also be considered as costs for storage (CS). Also, costs of the process (CP) itself for LS should be taken into account. As an example CP related to LS can be an increase in labor costs due to night shifts. Finally, if the costs related to LS are lower than a possible income from LS (ILS), the LS can be implemented in the industrial process. This criterion is given in the following (2):

$$CPC + CS + CP < ILS. \tag{2}$$

B. *Methodology for LS with VSM*

The main initial goal of LP and VSM was to reduce lead time (L/T), i.e, the time it takes to move a produced piece all the way in the process or production from start until to the end. As a result, many costs or wastes, as defined in LP, will be reduced. As shown in (2), income from LS should be higher than costs related to it because LS can increase the intermediate stock and due to that it has a negative effect on the L/T as well. VSM is a tool that will help to find the processes which have a reasonable effect and income. To achieve that, cost saving potential must be estimated. In section II, we showed a possible gain from LS in Estonia. The next step is to define the energy consumption of the processes. It is useful to combine that with VSM. If a company already has VSM, then energy consumption should be added into the VSM. VSM will highlight important information to be considered for LS. Most importantly, the following information must be taken into account:

a) Identify if the process is a bottleneck in production. If the process is a bottleneck, then load shifting is usually impossible without investment into the process output increase

b) Process cycle time (C/T) is slower or faster than its next process C/T. C/T in VSM describes how often a part or a product is completed by a process. If the process C/T is slower than the process coming next, it is possible to increase intermediate stock at the end of the process coming after rather than at the end of the first process. In case the first process is faster than the next one, the LS applied will increase the intermediate stock.

c) Weather process uptime (UPTIME) is high or low, shows important information about process reliability. A low reliability process has a negative effect on LS.

d) If stock between processes is high or low, the reasons should be found out before applying load scheduling.

e) Change over time (C/O) is long or short. C/O is the time period for switching the process unit from one product to another. It can show also time for cold start of the process. C/O can highlight important information about the process start up time.

The best way to start defining the energy consumption of a process is to make the consumer list. Consumer list should be based on processes described with VSM. The consumer list may be available in the facility electrical department. In that case, consumer list is usually based on the power cabinets and it has to be made process by process. If the consumer list is not available, it should be done from scratch. As the purpose is to find an initial energy intensive process, the consumer list can be composed without actual measurements. The consumer list should contain the following information: process name; device label; rated power; cos_{φ}; nominal current; nominal voltage and consumption type that can be either continuous, intermittent or stand by.

Upon completion of the consumer list, traditional VSM should be elaborated and total nominal loads in the process added. As a result, elaborated VSM will show which processes have sufficiently high energy intensity to gain benefits from LS and on the other hand, to estimate the particular potential to the process scheduling. After completing the estimation in conjunction with experts from production, the VSM should be elaborated further. Based on the measurements, energy intensity or the production unit is to be found. As the energy usage was previously estimated, measurements can be done in the production process where energy usage is estimated to be high or VSM shows that LS can be implemented without investing to process capacities or intermediate stocks.

As VSM describes product flow, the energy intensity should also be given per product or production unit. The unit energy consumption in the production process should be calculated based on the actual measurement. Fig. 2 shows a theoretical example of VSM together with data from the consumer list and energy intensity in the process. Energy intensity is energy consumption in each process to make one unit. As can be seen, process A C/T takes 2 minutes, i.e., one unit is completed during 2 minutes in the process. The total nominal power of the process is 30 kW and 2 kWh is consumed to make one unit. First intermediate stock capacity (after process A) is 10 pieces. It consists of 20kWh energy which is available for scheduling. Process B C/T is 4 minutes and the total nominal power in that process is 50 kW. As the second intermediate stock (after process B) capacity is 15 pieces, it has 75 kWh energy available for scheduling. Process C cycle time is 7 minutes, total nominal power is 2 kW and 0.3 kWh is consumed for making one unit. We can see that process A C/T is 2 times faster than process B and process C cycle time is 3.5 times faster than process A. As a result, we can conclude that the last process will dictate the whole process time and previous processes can be scheduled taking into account the possibilities of the last process. For that reason, we need to know how much time it takes to empty the intermediate stock before the slowest process, which we call buffer time (BT). In order to find BT, process C/T must be multiplied with an available intermediate stock capacity (ASC) (3) and (4).

$$ASC = MSC - SSC. \tag{3}$$

$$BT = C/T \cdot ASC. \tag{4}$$

ASC is a difference between maximum stock capacity (MSC) and safety stock capacity (SSC). SSC is to be defined by production management.

BT shows the maximum load scheduling period in the process. Neglecting safety stock capacity, in our example BT is 105 minutes. The total energy we can shift during 105 minutes is 95 kWh, which is the sum of stored energy in two intermediate stocks with 75 and 20 kWh accordingly.

IV. Experimental Load Scheduling Analysis in a District Heating Plant with Improved VSM Methodology

An example of the method above is described here. This example covers a district heating plant in Paide, Estonia. The company has one 8 MW woodchip boiler, several boilers fuelled with shale-oil and one CHP plant based on woodchips and with 8 MW thermal, 2 MW electrical output. Fig. 3 shows the process of the plant. Woodchip boiler stock (moving floor) is filled by a conveyor from the main storage (moving floor). The main storage is filled by the incoming tucks or a wheel loader. The company has 5-day storage available on site. Woodchip boiler stock can contain woodchips a day with boiler nominal load i.e. 180 m^3. The conveyor between the main storage and the woodchip boiler stock has a maximum output of 50 m^3/h. The conveyor from the woodchip boiler stock to the boiler has a strict limitation for processing output from the woodchip boiler. As it has no stock or daily silo available between the boiler and the conveyor, the output is 7.5 m^3/h with the nominal boiler load. We start the cost reduction estimation from LS by modeling the process using VSM as a basis. One cubic meter of woodchips is taken here as one unit in VSM.

According to the conveyor output parameters, the total output time is 6 days and 15.2 minutes and the value creating time is 17.2 minutes (time when one cubic meter of woodchips is actually processed). Also, the VSM shows that the conveyor from the main to the boiler stock has excessive capacity and is able to process one cubic meter of woodchips approximately 6.67 times faster than the process bottleneck, i.e. woodchip boiler.

The boiler will process one cubic meter of woodchips into heat in 8 minutes. It can be concluded from VSM that there is a possibility of LS of the conveyor from the main storage to the boiler stock. It must be emphasized that we are dealing with a biomass conveyor; therefore, the following simplifications are used:

a) woodchip processing by a boiler is calculated based on the nominal load, and boiler efficiency parameter is 0.8;

b) woodchip energy intensity is approximated at 1.3 MW/m^3, in real life it can be different, based on the fuel type and humidity level.

The next task is to estimate process energy intensity by making a consumer list behind the process. In our example, it is evident from VSM that the only process that can be scheduled is the process called “Conveyor from Main Stock to Boiler Stock”. Thus, we need to make a consumer list behind this process, which is given in Table I

Table I shows that the total nominal power behind the process is 73.5 kW. The consumer list is necessary to estimate of the process energy demand. It is possible that some consumer’s nominal power is much greater than the actual absorbed power. Therefore it is necessary to measure the process energy use.

TABLE I CONSUMER LIST FOR CONVEYOR FROM MAIN STOCK TO BOILER STOCK

Description	Pn	Cos ϕ	In	Un	Consumption
Conv. Screen to dist. Conv.	15	0.8	46.9	0.4	Continuous
Distr. conveyor	7.5	0.8	23.4	0.4	Continuous
Floor to conveyor motor	4	0.8	8.6	0.4	Continuous
Floor to conveyor motor	4	0.8	8.6	0.4	Continuous
Hydro pack	15	0.85	28.9	0.4	Intermittent
Hydro pack	15	0.85	28.9	0.4	Intermittent
Screen	5.5	0.81	11.4	0.4	Continuous
Conv. floor to screen	7.5	0.8	23.4	0.4	Continuous

In our example, Fluke 1735 is used for measurements of the process energy use and current measurements for some continuous consumption. There is calculated absorbed power with the following (5).

$$P = 3 \cdot I_f \cdot U_f \cdot cos_{\varphi}, \quad (5)$$

where P is absorbed power, I_f- phase current, U_f- phase voltage and $\cos_{\varphi}$ is power factor. By using absorbed power for a continuous load, energy consumption was estimated as well. Total energy consumption for processing 1 m³ of woodchips was 0.96 kWh. Complete VSM for the process examined is given in Fig. 3.

The VSM shows that by processing one cubic meter of woodchips there is consumed 0.96 kWh of electrical energy. As there is storage available with 180 m^3 and SSC is 7.5 m^3, ASC is 172.5 m^3 using (3). By knowing process C/T behind the intermediate stock- it is 8 minutes per m^3. There can be found out that BT is 23 hours by using (4).

We can conclude that BT is sufficiently long for considering LS from HPP to LPP given in section II. Paide boiler plant is connected to a grid at low voltage line, so the grid tariffs applicable will be different from those given in section II. HPPP for the current example is 83.4 euros per MWh with 43.5 euros per MWh grid tariff and LPPP is 55.2 euros per MWh with 25.7 euros per MWh grid tariff. Based on (1), we can calculate potential saving which is 33.8%

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In the previous example, the VSM process is not complicated; however, VSM is essential in case production is more complicated and processes are more complex and dependent on each other. In that case, VSM enables cost savings with LS. Moreover, LS is well understandable with VSM for staff involved in production management and planning.

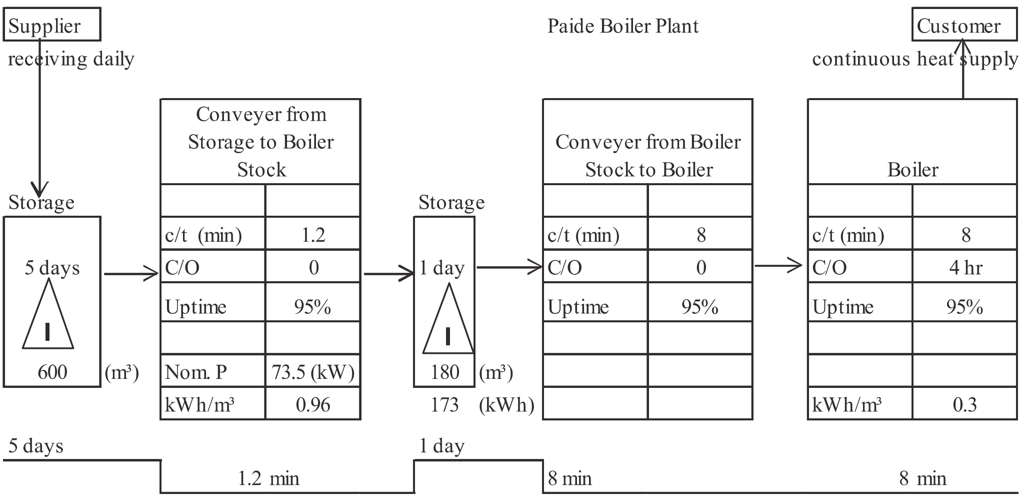

Fig. 3. VSM for LS for Paide district heating company.

V. CONCLUSION

Various aspects of DSR were studied. Focus was on the price difference in the electricity stock market in Estonia. If the loads are shifted from HPP to LPP LS will enable a cost reduction of 31%. The methodology based on VSM was introduced where cost savings were achieved with LS. Our analysis of experimental load scheduling was based on the district heating company in Estonia. The proposed methodology was found to be applicable as a straightforward tool to achieve cost savings. It can serve as first step for industry when implementing LS because of its simplicity. With minor costs, reduced time and lower complexity, a major cost saving can be achieved with simple solutions such as the method proposed.

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Paper III Melsas, R.; Rosin, A.; Drovtar, I. (2016). "Value Stream Mapping for Evaluation of Load Scheduling Possibilities in a District Heating Plant." Transactions on Environment and Electrical Engineering, 1 (3), 62−67.10.22149/teee.v1i3.34."

Value Stream Mapping for Evaluation of Load Scheduling Possibilities in a District Heating Plant

Raivo Melsas, Argo Rosin, and Imre Drovtar

***Abstract*— Demand side response enables cost optimization for energy systems and industrial consumers. In many countries, it is not widely used because of implementation complexity. One of the solutions for applying demand side response is industrial process scheduling according to the energy market needs. From the energy system point of view, process scheduling implies load scheduling. The aim of this paper is to provide a solution for load scheduling by implementing value stream mapping, which is a straightforward enough for production management. Decision makers in the industry should have a clear understanding about positive effect from load scheduling and its effect to production outcome and process availability. Value stream mapping is a well-known process optimization tool from lean production philosophy. The aim of value stream mapping is to shorten the lead time of industrial processes and to reduce the intermediate stock amounts. By complementing value stream map with process energy intensity and energy stored in intermediate stocks, we can promote load scheduling possibilities. Our methodology provides a tool that is understandable and traceable for industry-minded decision makers. Finally, we present a real life test example for the new methodology, which is based on the production process of a district heating plant.**

***Index Terms*— demand response, energy storage, load management, load scheduling, value stream mapping**

I. Introduction

LOAD scheduling (LS) as part of demand side response (DSR) must meet the needs of industry. One of the effects for the industry appears when load consumption is shifted from periods of high electricity price to those of low price. As a result, cost savings can be achieved by means of reduced consumer demand in high price periods. This requires better production planning, which is related to production management.

Previous DSR studies have resulted in the following: static Stackelberg game theory for voluntary load curtailment programs [1]; numerical calculation method for DSR when a battery energy storage system (BESS) is utilized [2]; solutions for DSR by means of automatic lighting [3]; DSR with micro-CHP systems [4]; an overview for DSR methods in high consumption industries and examples of market tools that support DSR [5]. In [6] an automated complex system for LS in industry is described, which takes into account stock restrictions, maintenance schedules, and crew management. All the necessary inputs are analyzed with a fuzzy/expert-based system combined with an optimization module. As a result, the system is able to identify whether and how much the industrial plant can participate in a DSR event. In [7] and [8] DSR is addressed as a part of the following main load shaping strategies:

a) *conservation - energy saving is achieved through static methods;*

b) *load growth - energy consumption is increased when an energy system has surplus energy production;*

c) *valley filling - load is increased through the off-peak periods or keeping stable consumption;*

d) *peak clipping - energy consumption is decreased in peak periods;*

e) *load shifting - peak consumption is shifted from peak periods to non-peak periods;*

f) *seasonal load reduction - annual energy peaks are reduced.*

LS is used mainly in “load shifting” strategy e; however, in some cases, “valley filling” strategy can be utilized as well. To use the LS, an industry must have the following one or several DSR options [8]: cooling equipment with cooling storage, heating equipment with heat storage, dual fuel systems that can operate either on electricity or on an alternative fuel, discretionary loads and process equipment that can be shifted during a short period or material handling equipment with storage possibilities (silos, stock, etc.). This paper focuses on the last option by looking at process as a whole in order to find LS solutions. In addition, it provides a method applicable in industry for outlining the possibilities with LS as a part of DSR by using value stream mapping (VSM). VSM is applicable in various ways. Originating from Toyota Production Systems [9], it was further elaborated and adjusted

This research was supported by the Estonian Centre of Excellence in Zero Energy and Resource Efficient Smart Buildings and Districts, ZEBE, grant 2014-2020.4.01.15-0016 funded by the European Regional Development Fund.

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to find solutions for different problems in the production process. For example, VSM is used to solve quality problems [10]. This paper elaborates on VSM. Our proposal is to use it for indicating a possibility to shift an electrical load from a high price period to a low price period and utilize an intermediate stock for energy storage [11], [12], [13]. This paper will provide a straightforward solution for the industry in order to apply LS effectively and which is easily applicable.

II. II. ENERGY PRICE AS A DRIVER FOR LOAD SHIFTING

LS can yield an economic effect under rational consideration. Cost reduction can be achieved by taking advantage of energy price fluctuations during a day. It is reasonable to have demand response implemented in countries where an electricity pool exists and hourly based spot prices are known for a short period ahead. As a result, industries can plan their production according to the spot price. Fig. 1 shows an average 24-hour electricity market spot price in Estonia in 2014 [14]. As can be seen, electricity spot price is typically higher from 07:00 A.M. to 8:00 P.M. In general, there is at least 10-euro price difference during a day and a night. Considering the price peak and dip approximately 20-euro difference per MWh exists during a day. On average, price difference during a day is 15-euro MWh.

However the consideration above includes only electricity price; in addition, there are some fluctuations in grid service price as well. From 12:00 A.M. to 8:00 A.M. (11:00 P.M. to 7:00 A.M. in winter time), the grid service price is lower. This period is not overlapping 100% with a low spot price period. We will call this period (12:00 A.M. to 8:00 A.M.) as the Low Price Period (LPP) and the other period during a day as the High Price Period (HPP). Grid tariffs depend on grid connection voltage level and connection capacity (amps). In the following, we will describe one example to examine the daily price difference for the industry in Estonia.

At substantial electricity consumption, an industry is usually connected into a middle voltage (MV) grid. In that case, Estonian grid service price is 14.5 euros per MWh from 8:00 A.M. to 24:00 A.M. and during LPP 8.3 euros per MWh [15]. For some customers, no time difference is applied; the price for grid services is constant in time- 12 euros per MWh. Fig. 1 shows both the grid price and the spot price fluctuations.

In 2014, an average electricity spot price for LPP was 29.5 euros per MWh and with grid price fluctuations it amounted to 37.8 euros per MWh, which we call as the Low Price Period Price (LPPP). In 2014, an average HPP spot price was 40.9 and together with grid tariff, the average number was 55.1 euros per MWh, which we call as the High Price Period Price (HPPP). For clarity, 55.1 is an average found on hourly bases, i.e. spot price + grid price.

Based on the data provided, we can calculate potential savings for industry under LS. Potential cost saving is 31%, which is calculated by (1):

$$CS = \frac{HPPP - LPPP}{HPPP}. \quad (1)$$

In general, it can be concluded that grid tariff fluctuation has an important role in LS in Estonia, as the average difference in the spot price between HPP and LPP was 11.4 euros per MWh and grid tariff will add extra for the difference between HPPP and LPPP, according to [15], tariff depends on the grid connection parameters.

The shape of the electricity spot price in Fig. 1 can be considered as a typical shape of the daily demand of electricity as well; a similar shape of demand can be found in various places, e.g., even in South Africa [16]. Thus, DSR has a positive impact to overall efficiency to energy systems, not only to an industry itself.

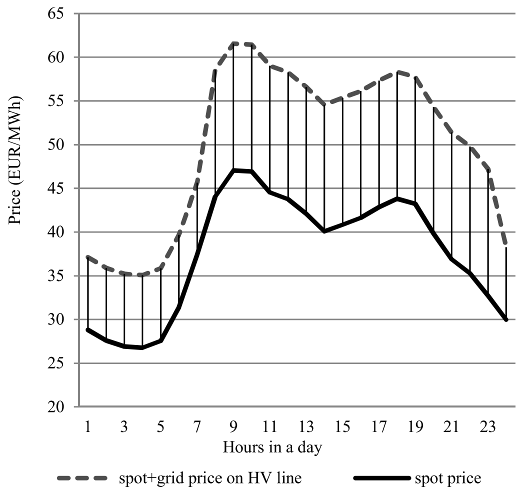

Fig. 1. Average Estonian 2014 electricity spot price during a day.

III. IMPROVEMENT OF VALUE STREAM MAPPING METHODOLOGY FOR EVALUATION OF LOAD SCHEDULING POSSIBILITIES

A. Load Scheduling at Intermediate Storage Use in Production

In the following, LS possibilities are examined for intermediate storage use as an energy saving unit, to enable shifting of energy intense production from HPP to LPP. In LS, it is important to understand energy intensive production units and their overall role in the production. Methods from lean philosophy [LP] can be used here. We propose to improve the value stream mapping (VSM) methodology with LS principles. Today LP is a leading production management philosophy. VSM is used to plan production as efficiently as reasonably possible. Energy intensity can be added in a process as additional information for a VSM, which will give a good overview about the possibilities in energy saving. Fig. 2 gives an overall picture of a typical VSM, elaborated with process energy intensity and amount of energy stored in the production intermediate storage.

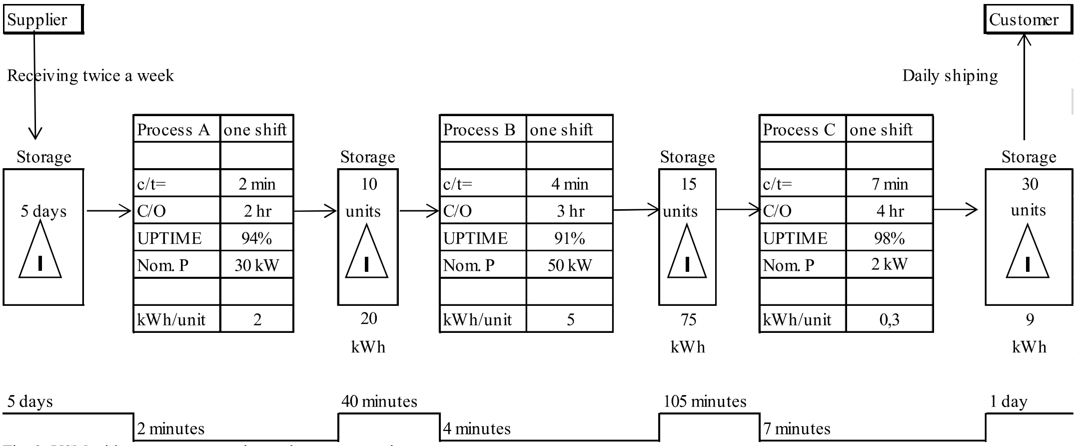

Fig. 2. VSM with energy consumption and storage overview.

As VSM gives an overview of the production planning and can additionally give information about energy intensity, the possibility of the LS should be studied in detail. From VSM, we will know if an energy intense process is at the same time a bottleneck in production. If it is not true, then the conclusion is that this process is not 100% utilized in time and LS can be implemented without increasing process capacity. Alternatively costs for increasing process capacity (CPC) need to be calculated.

Next, we focus on the storage. If production is shifted in time, storage volume can increase as compared to the state without LS utilized. Storage increase may need additional investments, which should also be considered as costs for storage (CS). Also, costs of the process (CP) itself for LS should be taken into account. As an example CP related to LS can be an increase in labor costs due to night shifts. Finally, if the costs related to LS are lower than a possible income from LS (ILS), the LS can be implemented in the industrial process. This criterion is given in the following (2):

$$CPC + CS + CP < ILS . \qquad (2)$$

B. Methodology for LS with VSM.

The main initial goal of LP and VSM was to reduce lead time (L/T), i.e, the time it takes to move a produced piece all the way in the process or production from start until to the end. As a result, many costs or wastes, as defined in LP, will be reduced. As shown in (2), income from LS should be higher than costs related to it because LS can increase the intermediate stock and due to that it has a negative effect on the L/T as well. VSM is a tool that will help to find the processes which have a reasonable effect and income. To achieve that, cost saving potential must be estimated. In section II, we showed a possible gain from LS in Estonia. The next step is to define the energy consumption of the processes. It is useful to combine that with VSM. If a company already has VSM, then energy consumption should be added into the VSM. VSM will highlight important information to be considered for LS. Most importantly, the following information must be taken into account:

a) *Identify if the process is a bottleneck in production. If the process is a bottleneck, then load shifting is usually impossible without investment into the process output increase.*

b) *Process cycle time (C/T) is slower or faster than its next process C/T. C/T in VSM describes how often a part or a product is completed by a process. If the process C/T is slower than the process coming next, it is possible to increase intermediate stock at the end of the process coming after rather than at the end of the first process. In case the first process is faster than the next one, the LS applied will increase the intermediate stock.*

c) *Weather process uptime (UPTIME) is high or low, shows important information about process reliability. A low reliability process has a negative effect on LS.*

d) *If stock between processes is high or low, the reasons should be found out before applying load scheduling.*

e) *Change over time (C/O) is long or short. C/O is the time period for switching the process unit from one product to another. It can show also time for cold start of the process. C/O can highlight important information about the process start up time.*

The best way to start defining the energy consumption of a process is to make the consumer list. Consumer list should be based on processes described with VSM. The consumer list may be available in the facility electrical department. In that case, consumer list is usually based on the power cabinets and it has to be made process by process. If the consumer list is not available, it should be done from scratch. As the purpose is to find an initial energy intensive process, the consumer list can be composed without actual measurements. The consumer list should contain the following information: process name; device label; rated power; $\cos_{\varphi}$; nominal current; nominal voltage and consumption type that can be either continuous, intermittent or stand by.

Upon completion of the consumer list, traditional VSM should be elaborated and total nominal loads in the process added. As a result, elaborated VSM will show which processes have sufficiently high energy intensity to gain benefits from LS and on the other hand, to estimate the particular potential to the process scheduling. After completing the estimation in conjunction with experts from production, the VSM should be elaborated further. Based on the measurements, energy intensity or the production unit is to be found. As the energy usage was previously estimated, measurements can be done in the production process where energy usage is estimated to be high or VSM shows that LS can be implemented without investing to process capacities or intermediate stocks.

As VSM describes product flow, the energy intensity should also be given per product or production unit. The unit energy consumption in the production process should be calculated based on the actual measurement. Fig. 2 shows a theoretical example of VSM together with data from the consumer list and energy intensity in the process. Energy intensity is energy consumption in each process to make one unit. As can be seen, process A C/T takes 2 minutes, i.e., one unit is completed during 2 minutes in the process. The total nominal power of the process is 30 kW and 2 kWh is consumed to make one unit. First intermediate stock capacity (after process A) is 10 pieces. It consists of 20kWh energy which is available for scheduling. Process B C/T is 4 minutes and the total nominal power in that process is 50 kW. As the second intermediate stock (after process B) capacity is 15 pieces, it has 75 kWh energy available for scheduling. Process C cycle time is 7 minutes, total nominal power is 2 kW and 0.3 kWh is consumed for making one unit. We can see that process A C/T is 2 times faster than process B and process C cycle time is 3.5 times faster than process A. As a result, we can conclude that the last process will dictate the whole process time and previous processes can be scheduled taking into account the possibilities of the last process. For that reason, we need to know how much time it takes to empty the intermediate stock before the slowest process, which we call buffer time (BT). In order to find BT, process C/T must be multiplied with an available intermediate stock capacity (ASC) (3) and (4).

$$ASC = MSC - SSC. \quad (3)$$

$$BT = C/T \cdot ASC. \quad (4)$$

ASC is a difference between maximum stock capacity (MSC) and safety stock capacity (SSC). SSC is to be defined by production management.

BT shows the maximum load scheduling period in the process. Neglecting safety stock capacity, in our example BT is 105 minutes. The total energy we can shift during 105 minutes is 95 kWh, which is the sum of stored energy in two intermediate stocks with 75 and 20 kWh accordingly.

IV. EXPERIMENTAL LOAD SCHEDULING ANALYSIS IN A DISTRICT HEATING PLANT WITH IMPROVED VSM METHODOLOGY

An example of the method above is described here. This example covers a district heating plant in Paide, Estonia. The company has one 8 MW woodchip boiler, several boilers fuelled with shale-oil and one CHP plant based on woodchips and with 8 MW thermal, 2 MW electrical output. Fig. 3 shows the process of the plant. Woodchip boiler stock (moving floor) is filled by a conveyor from the main storage (moving floor). The main storage is filled by the incoming tucks or a wheel loader. The company has 5-day storage available on site. Woodchip boiler stock can contain woodchips a day with boiler nominal load i.e. 180 m^3. The conveyor between the main storage and the woodchip boiler stock has a maximum output of 50 m^3/h. The conveyor from the woodchip boiler stock to the boiler has a strict limitation for processing output from the woodchip boiler. As it has no stock or daily silo available between the boiler and the conveyor, the output is 7.5 m^3/h with the nominal boiler load. We start the cost reduction estimation from LS by modeling the process using VSM as a basis. One cubic meter of woodchips is taken here as one unit in VSM.

According to the conveyor output parameters, the total output time is 6 days and 15.2 minutes and the value creating time is 17.2 minutes (time when one cubic meter of woodchips is actually processed). Also, the VSM shows that the conveyor from the main to the boiler stock has excessive capacity and is able to process one cubic meter of woodchips approximately 6.67 times faster than the process bottleneck, i.e. woodchip boiler.

The boiler will process one cubic meter of woodchips into heat in 8 minutes. It can be concluded from VSM that there is a possibility of LS of the conveyor from the main storage to the boiler stock. It must be emphasized that we are dealing with a biomass conveyor; therefore, the following simplifications are used:

a) *woodchip processing by a boiler is calculated based on the nominal load, and boiler efficiency parameter is 0.8;*

b) *woodchip energy intensity is approximated at 1.3 MW/m^3, in real life it can be different, based on the fuel type and humidity level.*

The next task is to estimate process energy intensity by making a consumer list behind the process. In our example, it is evident from VSM that the only process that can be scheduled is the process called "Conveyor from Main Stock to Boiler Stock". Thus, we need to make a consumer list behind this process, which is given in Table I

Table I shows that the total nominal power behind the process is 73.5 kW. The consumer list is necessary to estimate of the process energy demand. It is possible that some consumer's nominal power is much greater than the actual absorbed power. Therefore it is necessary to measure the process energy use.

TABLE I
CONSUMER LIST FOR CONVEYOR FROM MAIN STOCK TO BOILER STOCK

Description	Pn	Cos ϕ	In	Un	Consumption
Conv. Screen to dist. Conv.	15	0.8	46.9	0.4	Continuous
Distr. conveyor	7.5	0.8	23.4	0.4	Continuous
Floor to conveyor motor	4	0.8	8.6	0.4	Continuous
Floor to conveyor motor	4	0.8	8.6	0.4	Continuous
Hydro pack	15	0.85	28.9	0.4	Continuous
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Screen	5.5	0.81	11.4	0.4	Continuous
Conv. floor to screen	7.5	0.8	23.4	0.4	Continuous

In our example, Fluke 1735 is used for measurements of the process energy use and current measurements for some continuous consumption. There is calculated absorbed power with the following (5).

$$P = 3 \cdot I_f \cdot U_f \cdot \cos_\varphi , \qquad (5)$$

where P is absorbed power, If- phase current, Uf- phase voltage and $\cos_\varphi$ is power factor. By using absorbed power for a continuous load, energy consumption was estimated as well. Total energy consumption for processing 1 m^3 of woodchips was 0.96 kWh. Complete VSM for the process examined is given in Fig. 3.

The VSM shows that by processing one cubic meter of woodchips there is consumed 0.96 kWh of electrical energy. As there is storage available with 180 m3 and SSC is 7.5 m3, ASC is 172.5 m3 using (3). By knowing process C/T behind the intermediate stock- it is 8 minutes per m3. There can be found out that BT is 23 hours by using (4).

We can conclude that BT is sufficiently long for considering LS from HPP to LPP given in section II. Paide boiler plant is connected to a grid at low voltage line, so the grid tariffs applicable will be different from those given in section II. HPPP for the current example is 83.4 euros per MWh with 43.5 euros per MWh grid tariff and LPPP is 55.2 euros per MWh with 25.7 euros per MWh grid tariff. Based on (1), we can calculate potential saving which is 33.8%.

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In the previous example, the VSM process is not complicated; however, VSM is essential in case production is more complicated and processes are more complex and dependent on each other. In that case, VSM enables cost savings with LS. Moreover, LS is well understandable with VSM for staff involved in production management and planning.

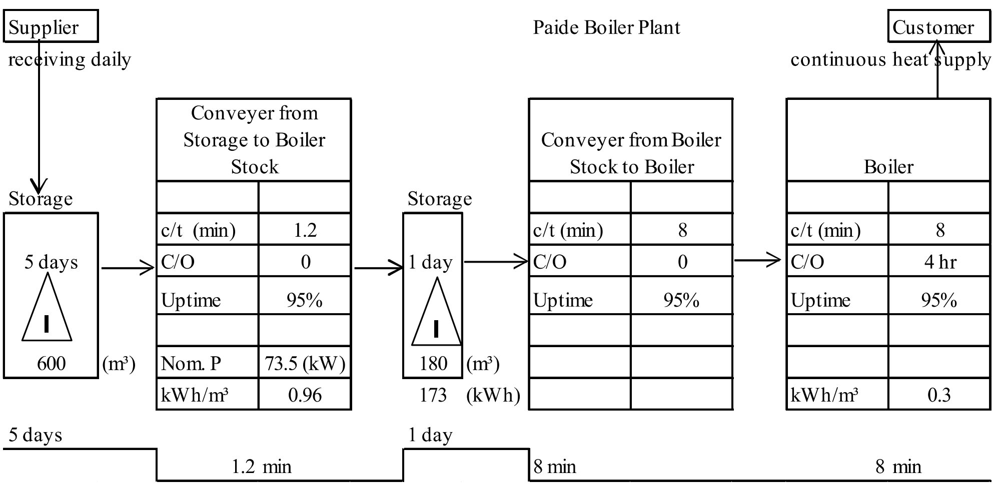

Fig. 3 VSM for LS for Paide district heating company..

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Paper IV R. Melsas and A. Rosin, "Use of value stream mapping for evaluation of load conservation and peak clipping possibilities," 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Milan, 2017, pp. 1-6. doi: 10.1109/EEEIC.2017.7977549

Use of Value Stream Mapping for Evaluation of Load Conservation and Peak Clipping Possibilities

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Abstract— **Energy efficiency is the focus for different organizations. On a global scale, it is related to climate change and initiatives towards reduction of greenhouse gases, such as Paris Agreement Within the United Nations Framework Convention on Climate Change. According to the agreement, each county has its targets on reduction of greenhouse gas emissions. By the United States Environmental Protection Agency, the share of greenhouse gas emissions from the energy sector is about 25%, which is the largest share. In terms of practice, the greenhouse gases can be reduced by the consumption of energy on the consumer level. The existing end user's energy efficiency methodologies often focus on the aspects of the consumer unit efficiency rather than on the energy efficiency of the whole system. Losses in installations and efficiency of subsystems before and after the consumer unit could be considerable. Therefore, commonly, methods are not used for both load conservation and scheduling analysis. We propose an improved value stream mapping methodology to evaluate energy saving of the whole system, by elaborating the load scheduling method described in our previous paper. Therefore, we propose a method for finding losses in three different aspects: reduction of losses before the consumer unit, reduction of losses in the consumer unit and reduction of losses behind the consumer unit. The improved method is described through an experimental example in a boiler plant with a simple process for woodchip conveying and stocking. Finally, we compare the method with other energy efficiency and peak clipping evaluation methods. The benefits of the method are that it combines different load shaping strategies into one method for energy savings.**

Keywords—energy consumption, energy conservation, demand side management, energy efficiency, load management.

I. Introduction

To apply demand side management in production it is required to give an overview and explain the solutions available. In our previous article [1], we have proposed to use the value stream mapping (VSM) for outlining load scheduling possibilities, as a part of load shifting strategy. Load shifting helps energy systems adapt unpredictable renewable energy producers by making energy systems smarter [2]. This study will elaborate the method proposed. We include other load shaping strategies called conservation and peak clipping. Load shaping strategies are described in [3] and [4] and consist of six different strategies: conservation, peak clipping, load growth, load shifting, valley filling, and seasonal load reduction. In our method, we will consider energy conservation and peak clipping strategy along with load shifting. In the peak clipping strategy, our assumption is that it is effective only if the reduction of losses is applied for processes functioning at high load periods. Our analysis also includes the benefits of the proposed methodology over alternative methods.

This work was supported by the Estonian Research Council grant PUT (PUT1680), and Centre of Excellence in Zero Energy ZEBE, grant TK146 funded by European Regional Development Fund.

II. Improvement of Value Stream Mapping Method for Load Shaping Strategies

In the previous paper [1], we examined the load shifting possibilities by using intermediate storages as an energy saving unit. The aim was to enable shifting of energy intense production from a high price period to a low price period. Energy intensity was added in the process as additional information for VSM. To define the energy consumption of a process, the consumer list was made. As a result, the VSM elaborated showed which processes have sufficiently high energy intensity to gain benefits from load scheduling and on the other hand, to estimate the potential of the process scheduling.

A. Reduction of losses for conservation and peak clipping

Here we will develop further the method for energy conservation and peak clipping. We will create a future value stream map, which will contain the process and product flow after applying load conservation or peak clipping. The possibilities for the implementation of the conservation and peak clipping strategy have been widely studied for specific consumption units for the energy conservation strategy. The studies show the efficiency of different technologies and compare them. For instance, in [5] LED lighting is described. Among other topics, the efficiency of LED lighting is analysed. An example of lumen and watt correlation in different lighting technologies is illustrated. Paper [6] describes an example based on the industrial facility lighting, [7] and [8] concentrate on the efficiency of electric motors, in [9], solutions for efficient HVAC systems in the high-tech industry were proposed. These studies explain well the energy savings for different specific technologies. We focus here on the energy saving possibilities on the consumer side independent of the specific technology. To concentrate on the consumer side, we will consider three different power conservation or peak clipping aspects given in Fig. 1.

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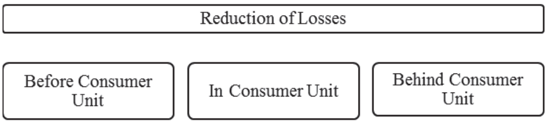

Fig. 1. Reduction of losses for energy conservation and peak clipping

Fig. 1 shows the following:

a) Reduction of losses before the consumer unit contains losses related to energy transfer from commercial energy measuring point up to consumer units. For example, it considers losses in cables, transformers and other elements in the supply network, starting from the distribution cabinet with a commercial energy meter.

b) Reduction of losses in the consumer unit. This aspect focuses on the consumer unit. The purpose is to detect less efficient technologies, such as inefficient motors, lighting, cooling and heating devices. We propose to list the consumer units in the consumer list, which allows definition of the efficiency of each unit. These efficiencies should be estimated based on the technical documentation or measurements of the devices. For example, by means of the measurements, it is possible to detect the correct dimensioning of the consumption units such as electrical motors. It is required to study reduction of losses from inefficient control. Control systems of devices and electrical motors should be detected, as a result, more efficient controlling solutions such as variable speed drives (VSD) can be used.

c) Reduction of losses behind the consumer unit are losses in the process. For example, if the process behind the consumer unit is a compressed air system, solutions to increase the efficiency of the system by reducing losses in the pneumatic system can be applied.

B. Consumer List For Load Mapping

To estimate the potential of conservation or peak clipping, proper methodology for load mapping in the sub-processes is required. We propose to use the "consumer list" for load mapping as described in Table I (an extended version of the consumer list is given in [1]). For conservation and peak clipping purposes, the consumer list contains the following data.

1. Description contains the name of the consumption unit and its process name.
2. P_N is the nominal power of the consumption unit, for example, data are needed for detecting dimensioning problems of the consumption unit.
3. P_M is an actual unit consumption in the working load. Data are needed for finding over-dimensioning problems.
4. V/C shows the dependence of consumption on the process output; it can be either constant or variable. In case the consumption is not dependent on the process output, it is constant; in other cases, it varies together with the process output. It becomes relevant at load shifting and calculating energy capacity stored in the intermediate storages in the process. Load shifting and use of intermediate storages as a kind of energy storage is described in [1].
5. E_C is the efficiency of the consumption unit in operation, for example, the efficiency of a motor, heating unit or lighting systems. The approach must be a specific type of a consumer unit; for example, we consider light system efficiency, which is watts per lumens delivered to the target area. This means that loss in reflectors and trapped light are also considered.
6. ΔPi is avoidable losses in the consumer unit; these can be, for example, coming from inefficient control of the devices or from efficiency decrease due to wrong dimensioning.
7. ΔP_S is the process loss behind the consumer unit, which can be, for example, losses in compressed air systems or losses in conveyors, as in our study. In efficiency calculations, comparison with the designed requirements should be made.

TABLE I.

CONSUMER LIST FOR CONVEYOR BETWEEN MAIN STOCK AND BOILER STOCK

Description	P_N, kW	V/C	E_C	P_M, kW	ΔP_i, kW	ΔPp, kW
M301- conv. screen to dist. conv.	15	Variable	87.7 %	2.7	0.14	0.64
M302- distr. conveyor	7.5	Variable	85.9 %	1.4	0.07	0.64
M1008- leveling roller	4	Variable	85.1 %	1.99	-	-
M1004- leveling roller	4	Variable	85.1 %	1.99	-	-
M1000- hydro pack	15	Variable	90.6%	9.09	-	-
M1001- hydro pack	15	Variable	90.6 %	11.87	-	-
M1003- screen	5.5	Variable	89.4 %	5.67	-	-
M-1005- conv. floor to screen	7.5	Variable	87.7 %	3.08	-	0.69
HID lamps	2.2	Constant	25 lm/W	-	1.67	-

After completion of the consumer list and VSM with energy consumption data, possible solutions for energy conservation and peak clipping strategy can be detected. As a result, cost-effective future VSM can be constructed as described in [1]. The future VSM should contain an action plan showing initiatives for load shifting and conservation strategies. Consumer list is based on the process outlined in Fig 3. The example process consists of woodchip storage, two conveyers and a boiler.

III. Example of Conservation and Load Shifting Strategy Application

A. Reduction of Losses Before Consumer Unit

In the following, we explain in more detail the load conservation strategies outlined in Fig. 1. Our experimental load conservation strategy for the process in Fig. 3 is called a conveyor from storage to the boiler stock. We explain the conservation strategy application by the experimental example. First, it is required to find saving possibilities for energy conservation in a local electricity distribution system that is between the distribution station and the consumer unit. Distribution stations should contain commercial measuring points for the energy consumption coming from the distribution system operator. Fig. 2 shows the distribution system for the consumer units given in Table I. Distribution losses consider losses in the lines and transformers from the commercial energy measuring point up to the consumption unit. Losses can be calculated based on the load measurements and components specifications of the distribution system. Losses for the lines and transformers can be calculated based on the engineering handbooks or using special calculation software. Another possibility is power measurement between the interconnection point and the consumption units. In most cases, distribution losses cannot be calculated for each consumer unit, as the distribution system may supply many consumer units.

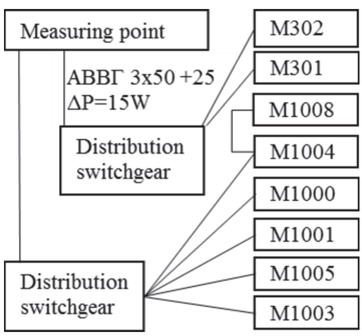

Fig. 2. Example of distribution system

As shown in Fig. 2, consumer units in our example are using two main lines to distribution switchgears. The measuring point is on the low voltage level. For that reason, there are no transformers in the transmission system. The losses in the lines are minor, i.e. calculated losses are less than 1 W with one exception. The line supplying two conveyors M301 and M302 has old type aluminum cable, as a result, power loss is 15 W. Table I shows that the power used on this line is 4.29 kW, which makes the loss of energy on the line 0.35%. 15 W power loss is not significant from the economic point of view for investments to change the cable in use. Thus, no actions are planned to reduce the distribution losses. In other cases where consumption loads are high and energy distribution systems contain also transformers, solutions for energy conservation can be applied.

B. Reduction of Losses in Consumer Unit

The second aspect from the three energy conservation possibilities, focuses on the reduction of losses in the consumption unit. We propose to use the consumer list shown in Table I for detecting a technology that is less efficient. The goal is to estimate ΔPi- avoidable losses in the consumer unit. These losses can be avoided by changing to a more efficient technology or by better control and operation of the consumer units. We propose a three-step approach to estimate the losses in the consumer unit.

Step 1 In the process, some consumer units are not directly related to the process output, moreover their usage can be related to many processes, such as lighting. From the process point of view, their energy usage is constant. For constant energy consumption units, it should be estimated how much of the consumer unit usage is related to the process. It is needed to have correct data in the consumer list, which are process dependent.

Step 2 Technology efficiency given in Table I as E_c should be estimated. Efficiency should be measured, if measurements are difficult in practice, it can be calculated. Calculations can be done based on the design documentations of the consumer unit.

Step 3 After energy usage is known, possible solutions for energy savings in the consumer unit should be estimated; in Table I it is described with ΔP_i. Energy savings can be achieved by installing a more efficient technology or a better operation of the consumer unit.

In our example, we have shown energy savings for two consumer unit types: electrical drives and electrical lighting. Table I gives the designed efficiency E_c of each consumer unit; in the following, we explain how ΔP_i is found.

1) Reduction of Losses in Electrical Drives

In step 1, all the motors in Table I are directly related to the process output; thus, their consumption is not constant from the process point of view. In step 2, motors have at least IE2 class according to standard IEC 60034-30-1. In step 2, we estimate the energy efficiency of existing consumer units. Some motors function at low efficiency because of over dimensioning. Table I shows that the measured load of consumer units M301 and M302 is remarkably lower than the nominal power. From Table I we know that the installed power is 15 kW and 7.5 kW; however, measured actual power is under 2.7 kW and 1.4 kW, accordingly. The measured power is given in Table I under the P_m column. We can conclude that motors are about five times over dimensioned. In a similar way, it is possible to find over dimensioning of other consumption units. Over dimensioning is the result of lower efficiency. Motors are working 19.07% from the nominal load. There are several methods available for the motor efficiency measurements, based on the standards such as in [10] or scientific like non-intrusive in [11]. Motors in our example are highly over dimensioned and function due to that at low efficiency level. According to [12], efficiency of the motor loaded 20% is about 5% less than in the nominal power. In step 3 in our example, we can conclude that the designed efficiency decrease of the motors is as follows: M301 from 92.3% to 87.7% and M302 from 90.4% to 85.9%. Lower efficiency contributes to the power losses in the consumer unit. For M301 with 2.7 kW load it is 135 W and for M302 motor with 1.4 kW load it is 70 W. In addition, the efficiency decrease from the consumer unit operation should be estimated as well. For example, VSD increases the efficiency of electrical drives by allowing motors to be operated at the ideal speed under any load condition. In many applications, VSDs reduce a motor's electricity consumption by 30–60% [13]. In the case of an industrial consumer, the load depends strongly on the load factor of the electrical machines, remaining around 50% to 60% from the rated power for mechanical processes [14]. In [12] it is reported that the efficiency of the motor is highest when it operates under 60 to 100% of the nominal load. Efficiency will decline when the motor operates under 50% of the nominal load. In [15], the choice principles for VSD are given and it is stated that thermal considerations of motor operation with a VSD should be of primary attention when choosing a VSD solution. The application of a VSD to a variable torque load such as a fan or centrifugal pump is more suitable, but constant torque or constant horsepower loads can cause motor overheating at reduced speeds. In our example, the conveyor application has no need for variable speed and the torque for the motors is independent of the motor speed. Thus, it is not our plan to change direct starting to VSD.

2) Reduction of Losses in Electrical Lighting

The last row in Table I considers lighting. It is sometimes difficult to estimate lighting in the production process, as it is often related to many processes and other supporting activities such as safety issues. As lighting can involve significant savings, it cannot be ignored in the estimation of energy consumption. When lighting is estimated in the processes, the quantity of lighting needed for the process and that for other processes should be determined. Furthermore, it should be taken into account that lighting is not always consumed when a process is activated. Sometimes consumption is independent of the process production output. In our example, lighting consumption is not related to the production process output. It is needed for safety reasons at night time, at annual heating periods. As the first step, we have considered only the part of lighting that is needed for conveyor lighting. In our case, there are seven lights involved in the process. The lights are high pressure sodium (HPS) type with a consumption load of 2.2 kW. In the second step, we estimate the efficiency of installed lights. According to [16], installing LED lights instead of HPS lights delivers 76% of system efficiency. LED lights deliver about 100 lumens per watt. In the third step, we estimate a more efficient technology. We can consider that LED technology is over three times more efficient and only 0.53 kW installed LED lights are needed to obtain the same lighting effect. This results in 1.67 kW of savings in lighting, as shown in Table I. The energy efficiency increase from better light operation has not been considered in the current example, as the lights are turned on due to safety instructions in the conveyor area.

C. Reduction of Losses Behind Consumer Units

Conservation strategy can be implemented by means of reducing losses behind the consumer unit. To find out losses behind the consumer unit requires detailed knowledge of the systems. The basic idea behind estimating many kinds of losses is in the comparison of the designed or calculated consumption between actual measured power consumption. The difference between the two will define the losses behind the consumer unit, as expressed in (1):

$$P_l = P_{mc} - P_d \tag{1}$$

where P_l is extra power to cover losses behind the consumer unit, P_d is the power calculation made based on the design data of the system and P_{mc} is actual measured power used by the system behind the consumer unit.

To find out losses in the conveyors and ΔP_p, Table I presents the designed power need for the conveyors and compares it with the measured power [17]. To find P_{mc}, we have measured the consumption unit load (P_m). Consumer unit efficiency denoted by E_c was found in section B. P_{mc} that considers the efficiency of the consumer unit calculated by equation (2):

$$P_{mc} = P_m \cdot E_c \,. \tag{2}$$

In our example, P_{mc} equals 0.84 kW for M1005, 0.67 for M302 and 0.45 for M301. Based on (1), we can calculate the power loss behind the consumer unit, which is 1.96 kW, 26% from the measured power P_m. Losses in the system for the other units in the consumer list are not considered significant. This is because M1003, M1004 and M1008 have circulating rollers and losses there come mostly from the faults of the bearing or faults of the transmission gears. Such faults can be detected by making vibration measurements; however, in our example, no faults were detected. For hydro power units, no leakages or malfunction of the devices were detected, so the system losses compared to the design were not found.

D. Conservation and Peak Clipping Strategy Potential

Above, we have shown the example of energy conservation possibility based on the woodchip conveyor process. Table II shows the potential of the conservation strategy in a concentrated way. As can be seen, three energy conservation methods have given results. The table does not consider the economic reasons and shows only the potential.

TABLE II. POTENTIAL ENERGY CONSERVATION AND PEAK CLIPPING STRATEGY WITH FUTURE VSM

Reduction of losses	**Description**	**Conservation potential, kW**
In supply	Line supplying M301&M302	-0.015
In a consumer unit	Overdimensioned motors and lighting efficiency	-1.63
Behind a consumer unit	Conveyors inefficiency	- 1.96

IV. Future Value Sream Map With Load Shifting and Energy Conservation Strategy

In section II we have proposed a methodology for the implementation of the energy conservation strategy using VSM. The future VSM shows the production processes with the effect from energy saving solutions and applied intermediate storages as an energy storage in the production processes.

Fig. 3 describes the future VSM with a plan to use the process named "Storage to boiler" for load scheduling according to [1] and to implement the conservation strategy. It is planned to reduce the losses behind the process of the wood chips supply from the main storage to the boiler stock. Table II shows the results of the possible savings. The only economically feasible solution for energy saving is to reduce the losses behind the consumer unit. The initial variable consumption (IVC) in the process is 0.96 kWh/m^3. By increasing energy efficiency in the process 0.04 kWh/m^3, variable relative energy reduction (VRR) is 4.2%. So, the future variable energy consumption (FVC) is 0.92 kWh per 1m^3 of wood chips. Conveyors are working during the heating period, which is about seven months. The conveyor process of 1 m^3 of woodchips within 1.2 min called the cycle time is given in Fig 3 as (Cycle. t.). The conveyor fast cycle time compared with the boiler results in the conveyor annual work hours of about 756 and annual variable energy consumption reduction (AVR) is 1524 kWh.

Fig. 3 shows the constant consumption in the process as well, i.e. the consumption which is independent of the processed m^3 of woodchips. This consumption results from lighting. Initial constant energy consumption (IFC) is 2.2 kW. It is proposed to use more efficient lighting; estimated future constant energy consumption (FFC) would be 0.53 kW, which constitutes a decrease of constant relative energy consumption (FRR) of 76%. The total of dark hours in the heating period is 3254 h, which is calculated based on the sunrise and sunset times in the conveyor location. Annual constant energy consumption reduction (AFR) is equal to 5434 kWh.

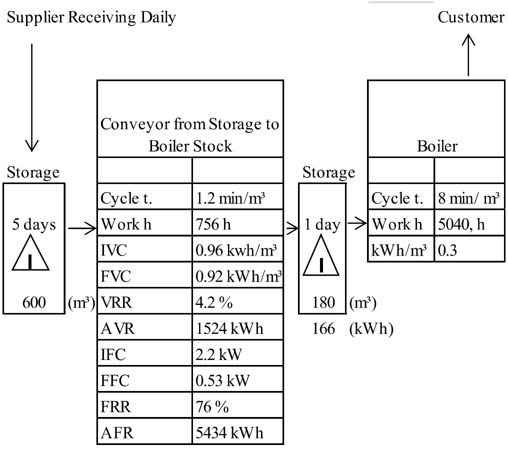

Fig. 3. Example of future VSM

V. Comparison of the Proposed Method with Other Methods

In the proposed VSM method for the load scheduling and conservation strategy, an energy cost saving tool was combined. This tool is visual and has load conservation and shifting in one methodology. Table III compares the proposed solution with other alternatives from three aspects: consideration of the load scheduling strategy; taking into account load the conservation strategy and availability of visualization description in order to show the implementation of load scheduling or conservation strategy.

TABLE III COMPARISON OF THE PROPOSED METHOD

Methodology description	Involves load scheduling	Involves load conservation	Visual
Proposed VSM	Yes	Yes	Yes
Alternative 1 Real Time Control	Yes	No	No
Alternative 2 Quantitive Analysis	Yes	No	No
Alternative 3 Audit Plan	No	Yes	Yes

Alternative 1 "Real Time Control" described in [18] proposes a solution for implementing load shaping strategy based on the real-time control of the processes by means of programmable logic controllers.

Alternative 2 "Quantitative Analysis" described in [19] focuses on the automotive industry and considers load scheduling together with the estimation of the whole process and its bottlenecks and intermediate storage buffers through continuous flow models.

Alternative 3 "Audit Plan" in [20] describes energy audit plan and energy conservation strategy execution. Also, it provides measurement of the conservation effect and possible visualization forms for showing the effect from conservation.

VI. Conclusion

We propose a combined method for load scheduling and energy conservation. Load scheduling methodology was described in an earlier paper with the energy conservation strategy. Energy conservation strategy was divided into three different aspects: reduction of power losses before the consumer unit, reduction of losses in the consumer unit, and reduction of losses behind the consumer unit (which are systems and processes behind the electrical devices).

The method was tested with an example of the heat production process consisting of a woodchips conveyor, an intermediate storage and a biomass boiler. The conservation solution and a boundary of the solution are described in detail. The test example outlines the energy conservation potential.

Finally, the effect of the peak clipping and energy conservation strategy on the process is described with the future value stream map known from lean production philosophy. Not all energy conservation solutions are considered in the future value stream map, as some of the conservation solutions are not economically feasible for implementation. The feasible solution in our example is the reduction of losses behind the consumer unit, resulting in 4.2% energy savings in the process related directly to the production process output. Constant energy consumption can be reduced by 76% due to the more efficient lighting solution. Constant energy consumption means that it is not related to the process output.

The study compares the proposed method with three alternative ways either for load scheduling or energy conservation methodology. The results of the comparison show that the proposed methodology is unique compared to the alternatives, combining three aspects in one methodology: load scheduling, energy conservation and visual description.

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Curriculum vitae

Personal data

Name: Raivo Melsas
Date of birth: 15.12.1979
Place of birth: Tallinn, Estonia
Citizenship: Estonian

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Education

Educational institution	**Graduation year**	**Education (field of study/degree)**
Tallinn University of Technology	2006	Master of Science in Electrical Power Engineering
Tallinn University of Technology	2003	Bachelor of Science in Electrical Power Engineering
Valga Gümnaasium	1998	high school education

Language competence

Language	**Level**
Estonian	Native language
English	Fluent
Russian	Basic

Professional employment

Period	Organization	Position
03.2017	Adven Eesti AS	Head of the Production and Distribution, Member of the Board
08.2012-03.2017	Eesti Energia AS, Taastuvenergia ettevõte and its subsidiaries: Pogi OÜ; Aulepa Tuulepark OÜ	Head of Production Member of the Board: Pogi OÜ and Aulepa Tuulepark OÜ
11.2008-08.2012	ABB AS, Low Voltage Systems	Operations manager
05.2005-11.2008	OÜ Jaotusvõrk, dispatch centers	Deputy manager/ Manager
05.2002-05.2005	OÜ Jaotusvõrk, dispatch centers	Engineer/ Senior Specialist

Elulookirjeldus

Isikuandmed

Nimi: Raivo Melsas
Sünniaeg: 15.12.1979
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Hariduskäik

Haridusasutus	**Lõpetamisaasta**	**Haridustase**
Tallinna Tehnikaülikool	2006	Magister, Elektroenergeetika instituut
Tallinna Tehnikaülikool	2003	Bakalaureus, Elektroenergeetika instituut
Valga Gümnaasium	1998	Keskharidus

Keelteoskus

Language	**Level**
Eesti keel	Emakeel
Inglise keel	Kõrgtase
Vene keel	Keskmine tase

Teenistuskäik

Periood	Tööandja	Ametikoht
03.2017	Adven Eesti AS	Tootmise ja jaotuse valdkonna juht, juhatuse liige
08.2012-03.2017	Eesti Energia AS, Taastuvenergia ettevõte ja selle ettevõtted: Pogi OÜ; Aulepa Tuulepark OÜ	Tootmisjuht; Juhatuse liige: Pogi OÜ ja Aulepa Tuulepark OÜ
11.2008-08.2012	ABB AS, madalpingesüsteemide tehas	Tootmisjuht
05.2005-11.2008	OÜ Jaotusvõrk, juhtimiskeskus	Juhataja asetäitja ja juhataja
05.2002-05.2005	OÜ Jaotusvõrk, juhtimiskeskus	Insener/ Juhtiv spetsialist