DEVIATION IN ENERGY CONSUMPTION ON AGGREGATE PRODUCTION PLANNING LEVEL IN INDUSTRIAL PRACTICE

Hajo Terbrack
Thorsten Claus
Technical University of Dresden
Faculty of Business and Economics
International Institute (IHI) Zittau
Markt 23, 02763 Zittau, Germany
E-Mail: hajo.terbrack@mailbox.tu-dresden.de

Frank Herrmann
Ostbayerische Technische Hochschule Regensburg
Faculty of Computer Science and Mathematics
Innovation and Competence Centre for Production
Logistics and Factory Planning (IPF)
Prüfeninger Str. 58, 93049 Regensburg, Germany

KEYWORDS

Energy Consumption, Aggregate Production Planning

ABSTRACT

In this article, we discuss energy consumption of producing firms on aggregate production planning. While almost constant energy consumption can be the case for a producing firm, highly fluctuating energy demand can occur as well. Together with volatile energy supply, e.g. due to renewable energy sources, this combination of fluctuating energy supply and demand can result in planning uncertainty and high energy costs. We propose different case studies in which such high deviation in the electricity consumption of a producing firm occurs due to aggregate production planning without appropriate consideration of energy consumption.

INTRODUCTION

Global energy consumption and respectively its costs are rising and therefore, the need to integrate energy consumption in industrial production planning is given. Without consideration of energy usage in production planning, highly fluctuating energy demand can arise. While energy suppliers already face problems in controlling energy supply, potential deviation in energy demand can strengthen planning uncertainty. As a result, high costs occur for energy suppliers to stabilize the power grid, leading to higher energy costs for the demand side, e.g. producing firms.

Within industrial production planning, a common concept is the hierarchical production planning as proposed by Hax and Meal in 1975 and many others (e.g. Claus et al. 2015). In this concept, the aim is to harmonise decisions that are necessary in the long term and that span multiple production sites, right up to short-term, to-the-second decisions at the plant level, across three planning levels: Production Program Planning (consisting of Aggregate Production Planning and Master Production Scheduling), Lot Sizing and Scheduling. Thereby, aggregate production planning (APP), as the upper level within production program planning, aims to smooth employment over a planning horizon of usually one to two years. Seasonally varying demand or possible economic fluctuation are taken into account in this mid-term planning. Based on product types and a typical period length of one month, capacity planning for one or more production sites is fulfilled. Besides an optimization of inventory level costs and costs for the usage of additional capacity, further optimization goals within APP can include transports between production sites, external procurement or multi-level supply processes.

To improve the planning situation for energy suppliers, mid-term production planning should consider energy consumption. Therefore, this article discusses energy consumption on aggregate production planning.

The article is structured as follows. Chapter 2 gives an overview of relevant literature on industrial energy usage and demand side management approaches on production program planning. Chapter 3 shortly introduces the APP optimization model used for the case studies, which are presented and discussed in Chapter 4. In Chapter 5, the paper concludes with a brief summary and an outlook for further research.

PROBLEM DEFINITION AND LITERATURE

With the ongoing integration of renewable energy sources, which are characterised by a very volatile supply, in the power grid (see Kabelitz et al. 2014, Simon 2017), corresponding fluctuations in the generation and feed-in of electricity from renewable energy sources are increasingly putting a strain on the electricity grids of electricity suppliers, who have to balance out irregular load distributions accordingly (see Paulus & Borggrefe 2011). In addition to this volatile electricity supply, strong fluctuations in the amount of energy purchased by the demand side can occur, as it can be the case with producing firms (see U.S. Department of Energy 2006). Together with increasing and strongly varying energy prices (see Rösch et al. 2019, Simon 2017), both, the energy supplier and the producing firm have to face planning uncertainty resulting in grid overloads and high costs for energy as part of total production costs. To improve power grid stability and to reduce the resulting costs, the energy demand side is more and more willing to involve energy costs and consumption into its planning (see Paterakis et al. 2017, Paulus & Borggrefe 2011) – as it is also the case for producing firms by corresponding production planning and control. Various so-called "Demand Side Management" (DSM) or "Demand Response" (DR) approaches pursue the goal of leading the demand side in the electricity market to change its

Communications of the ECMS, Volume 34, Issue 1,
Proceedings, ©ECMS Mike Steglich, Christian Mueller,
Gaby Neumann, Mathias Walther (Editors)
ISBN: 978-3-937436-68-5/978-3-937436-69-2(CD) ISSN 2522-2414

consumption in order to, among other things, take into account the strong fluctuations in electricity supply or to shift the use of electricity to periods with lower demand (see Paterakis et al. 2017, Paulus & Borggrefe 2011).

Within hierarchical production planning, different DSM approaches can be assigned to the respective planning levels, a large part of which are assigned to the scheduling level (see Biel & Glock 2016). However, since production quantities and available production capacities are already defined in lot sizing and scheduling where the planning horizon usually corresponds to one week, there is limited room for action at these lower levels of hierarchical production planning (see Claus et al. 2015, Günther & Tempelmeier 2016). In order to also achieve improved energy-oriented planning in the medium term, appropriate measures are necessary within production program planning.

Within aggregate production planning, there are only a few articles that focus on sustainability and in specific, on energy consumption. Cheraghalikhani et al. (2019), who present a literature review on aggregate production planning models, point out the open research issue of adding sustainability as well as green concepts to aggregate production planning. A DR approach within aggregate production planning is pursued by Latifoğlu et al. (2013) in their article. The authors present an approach that considers the effects of "Interruptible Load Contracts" (ILCs) at the level of aggregate production planning. A robust production plan is set up to meet all customer needs despite supply-side interruptions in the electricity supply, while minimizing electricity costs by taking the economic incentives of ILCs into account. Modarres and Izadpanahi (2016) present a robust optimization approach to minimize operational costs, energy costs and carbon emission in aggregate production planning. Under consideration of uncertain costs, energy and carbon parameters and uncertainty in demand and maximum capacity, the robust optimization approach is applied to a smelting manufacturer and the relationship between budgets of uncertainty and optimal values is analysed. In the article of Chaturvedi (2017), different production facilities are assumed with different facility-specific energy consumption rates per produced unit. By determining the optimal production capacity of each production facility through linear programming, the overall annual energy consumption is minimized while the demand is satisfied. An approach to maximize profit in aggregate production planning by consideration of labor costs, inventory costs, production costs, shortage costs and electricity costs is presented by Nour et al. (2017). The effect of electricity price changes on a porcelain manufacturer is analysed and total costs can be reduced by 23% compared to the former production planning.

However, none of the approaches presented can sufficiently reduce the deviations in the energy consumption of a manufacturing company in the medium-term production programme planning. Furthermore, due to the lack of a possibility to predict the existing energy supply with satisfactory accuracy in the medium term (see Kabelitz et al. 2014), the demand for electricity cannot be adjusted to supply forecasts in the medium term.

ENERGY-ORIENTED AGGREGATE PRODUCTION PLANNING

To integrate energy consumption into a common production program planning model, the aggregate production planning model AGGRPLAN, a linear optimization model, is expanded (for a detailed description see Claus et al. 2015). The basic model aims at smoothing employment over a planning horizon of several months by optimizing production quantities for product types in order to minimize costs for inventories and costs for additional capacity usage. We introduce product-type-specific energy consumption coefficients. These coefficients represent the electricity consumed in production of one unit of the corresponding product type. Energy consumption is considered in terms of production quantities multiplied with energy consumption per produced unit.

CASE STUDIES

To point out the relevance of high deviation in energy consumption of a producing firm, three case studies are presented. In these case studies, aggregate production planning is fulfilled resulting in fluctuating energy consumption. Additionally, a fourth scenario is described in which almost constant energy consumption occurs in aggregate production planning.

Case study (1) deals with the production of agricultural machines. A company in Germany produces two product types, ploughs, and hay rakes. Ploughs are necessary on the field to loosen and turn the soil before seeds can be sown. Hay rakes are frequently used to gather harvested material such as hay or straw for later collection. These agricultural product types are usually ordered by agricultural cooperatives and by individual farmers. In the manufacturing company, the production of these two product types is organised as a job-shop with six production segments and a total of 13 production machines. The layout of the shop floor is illustrated in Figure 1.

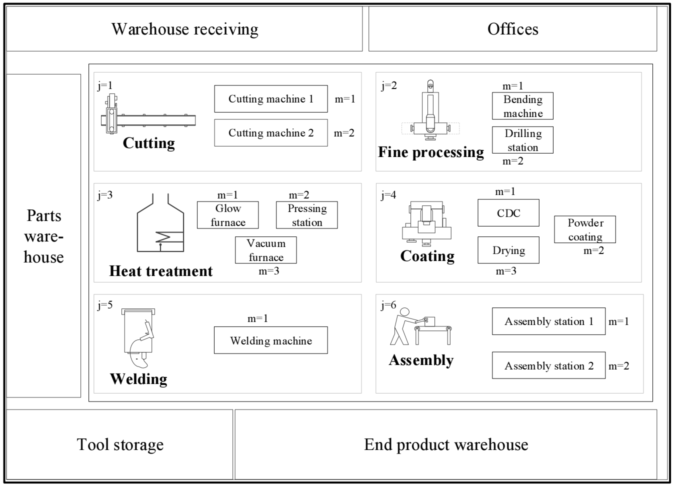

Figure 1: Shopfloor layout – case study (1).

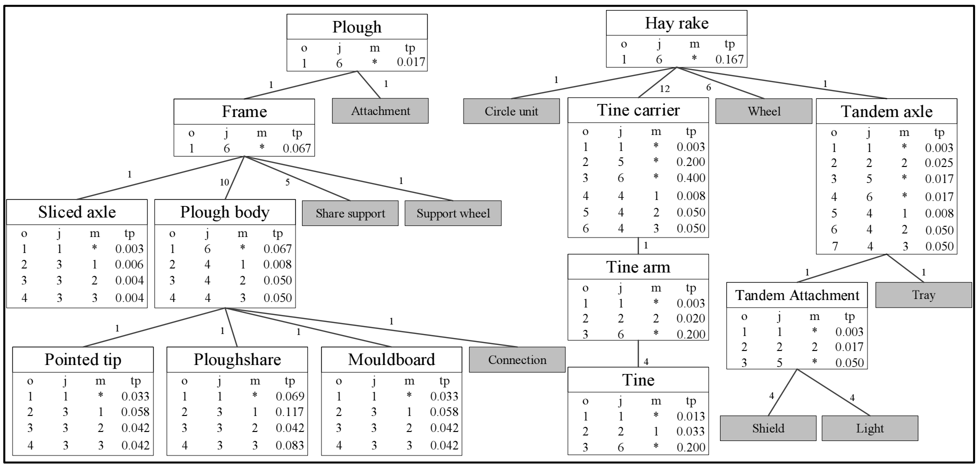

Figure 2: Gozintograph for product type 1 (plough) and product type 2 (hay rake) - case study (1).

A two-shift model is used whereby ten workers are available each shift. Gozintograph and corresponding processing times (*tp*) are stated in Figure 2. Column *o* represents the sequence of processing steps, *j* and *m* the production segments and machines as named in Figure 1. *tr* equals processing time on the machines in time units [TU]. Processing steps that can be carried out by all machines within a production segment are labelled with *. Purchase parts are shaded grey.

Throughput time of each product type was used as technical production coefficients in aggregate production planning. Therefore, by simulating material requirement planning and scheduling for 720 periods (representing 24 APP periods with an aggregation factor of 30) based on same demand data later used in aggregate production planning, throughput time was determined for each product type. Mean value and deviation is shown in Table 1. To determine personnel production coefficients, net processing times of each product type were analysed and referred to personnel and technical capacity usage. Based on the proportion of personnel and technical capacity usage, personnel production coefficients were calculated by multiplying the relation of personnel and technical net processing time with the mean value of throughput time. Summed up personnel and technical net processing times as well as energy consumption for producing one unit of each product type are shown in Table 2.

Case study (1) – Throughput time [in time units]	Mean value	Deviation
Plough	182.22	31.41
Hay rake	202.10	39.71

Table 1: Throughput time [in TU] – case study (1).

Case study (1) – Net processing times [in TU] and energy consumption [in EU]	Personnel	Technical	Energy Consumption
Plough	0.55	0.93	73.01
Hay rake	1.60	1.66	18.24

Table 2: Net processing times [in TU] and energy consumption [in EU] – case study (1).

Energy consumption in energy units [EU] per quantity unit of each product type was determined by calculating the electricity consumption of the corresponding production processes. Note that the production of ploughs is by far more energy-intensive than the production of hay rakes since the main components (ploughshare, sliced axle, pointed tip, and mouldboard) get heated, pressed, and hardened due to their need of being very robust.

In Table 3, the relevant product type parameters for case study (1) are stated. f_k^P represents personnel capacity usage in time units, f_k^T technical capacity usage in time units and f_k^E the consumed energy in producing one unit of the product type, in energy units. Inventory holding costs per quantity unit and APP period, h_k, are 140 money units (MU) for product type 1, ploughs, and 80 MU for product type 2, hay rakes. The initial inventory level is zero for both product types k ($I_{k0} = 0$).

Case study (1) – Product type parameters	f_k^P [in TU]	f_k^T [in TU]	f_k^E [in EU]	h_k [in MU]
Plough	106.67	182.22	73.01	140
Hay rake	195.52	202.10	18.24	80

Table 3: Product type parameters – case study (1).

Available capacity per APP period (personnel capacity b_t^P, maximum additional personnel capacity U_t^{max}, technical capacity b_t^T) and cost rate for additional capacity usage (u_t) is shown in Table 4.

Case study (1) – Capacity parameters	b_t^P [in TU]	U_t^{max} [in TU]	b_t^T [in TU]	u_t [in MU]
per APP period	3200	800	6240	36

Table 4: Capacity parameters – case study (1).

Aggregated demand quantities for each APP period are given in table 5. While different demand scenarios can occur, the assumed quantities represent a typical demand trend of the analysed company.

Fulfilling the aggregate production planning model AGGRPLAN leads to an optimization of inventory holding costs and costs for additional capacity usage. Figure 3 shows inventory levels per period, personnel capacity usage as well as the energy consumption for a planning horizon of 24 APP periods. Capacity usage is almost constant over the planning horizon and inventory level is fluctuating depending on the amount of pre-production. A deviation in energy consumption per APP

APP Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Plough	8	9	6	5	13	9	15	4	9	7	17	12	13	10	8	7	10	3	12	15	14	13	8	8
Hay rake	14	10	15	15	5	9	6	12	10	13	9	7	10	18	12	15	11	14	10	8	7	6	14	15

Table 5: APP demand quantities – case study (1), scenario (1).

period of 26% was measured, the difference between maximum and minimum energy consumption equals 823 EU and the average energy consumption is 914 EU.

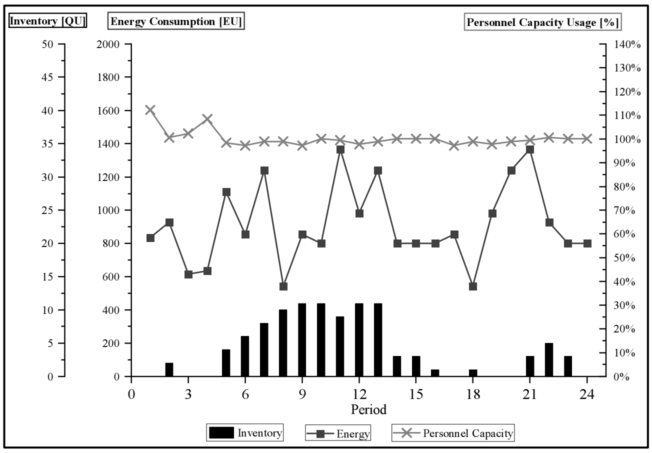

Figure 3: APP resulting in high deviation in energy consumption – case study (1), scenario (1).

In a second scenario, assuming a different demand structure, aggregate production planning was carried out for twelve APP periods. The new demand situation is given in Table 6. In this second scenario, customer demands and its mix are quite stable along the planning horizon. As a result, the corresponding energy consumption per period is less fluctuating (see Figure 4) with a deviation equal to 8%.

APP Period	1	2	3	4	5	6	7	8	9	10	11	12
Plough	8	9	8	7	8	9	8	7	7	7	8	7
Hay rake	14	12	13	14	14	9	13	12	10	16	9	12

Table 6: APP demand quantities – case study (1), scenario (2).

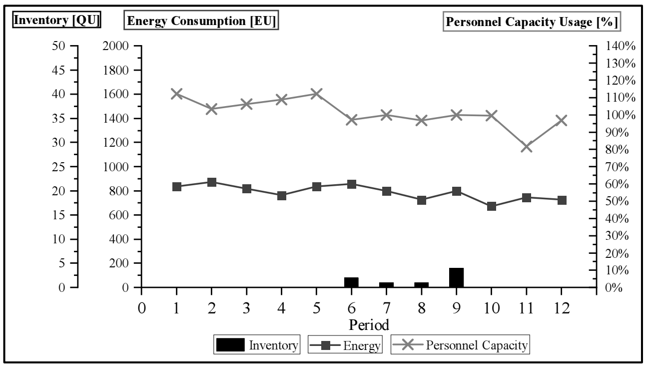

Figure 4: APP resulting in almost constant energy consumption – case study (1), scenario (2).

This case study (1) shows, that the combination of two product types with considerable differences in energy consumption and a varying demand structure can lead to high deviations in energy demand. As already mentioned, such huge differences in energy consumption can strengthen the planning uncertainty for the electricity provider and lead to high energy costs for a producing firm.

Case study (2) discusses the manufacturing of three components for plant construction in a company in Poland. 22 workers produce pipings, conveyor lines and carousels in a two-shift model, whereby eleven machines are ordered as a job shop with five production segments. Shop floor layout is outlined in Figure 5. Corresponding gozintographs and work schedules are stated in Figure 6 and 7.

The finished components are later installed in larger machines, such as bottling machines. Usually, multiple units of pipings and conveyor lines get installed in such machines and represent the main part of customer demand for the company. While production of pipings and conveyor lines do not differ much in energy usage due to almost similar process steps like cutting, sawing, drilling and bending, milling and welding of the inner and outer ring of the carousel lead to a high energy usage in production of carousels.

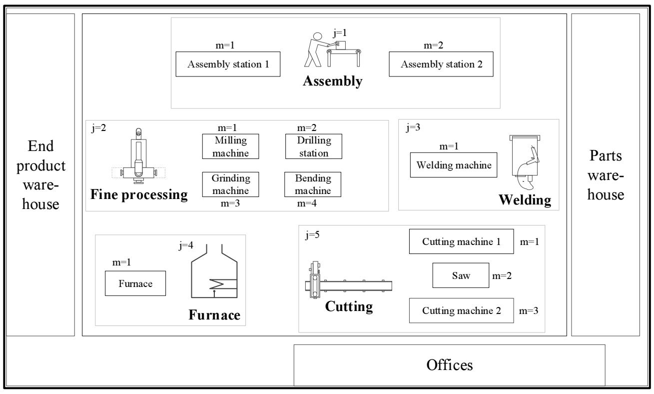

Figure 5: Shop floor layout – case study (2).

Production coefficients were determined by simulation equivalent to case study (1). MRP and scheduling was simulated for 360 periods (equal to 12 APP periods with an aggregation factor of 30) on the basis of demand data later used for APP. Mean value and deviation of throughput times are shown in Table 7, net processing time and energy consumption for each product type is listed in Table 8.

Case study (2) – Throughput time [in time units]	Mean value	Deviation
Piping	180.78	32.64
Conveyor line	178.97	35.71
Carousel	183.60	28.25

Table 7: Throughput time [in TU] – case study (2).

Case study (2) – Net processing times [in TU] and energy consumption [in EU]	Personnel	Technical	Energy Consumption
Piping	2.63	2.63	13.70
Conveyor line	2.04	2.04	4.90
Carousel	14.54	20.16	443.82

Table 8: Net processing times [in TU] and energy consumption [in EU] – case study (2).

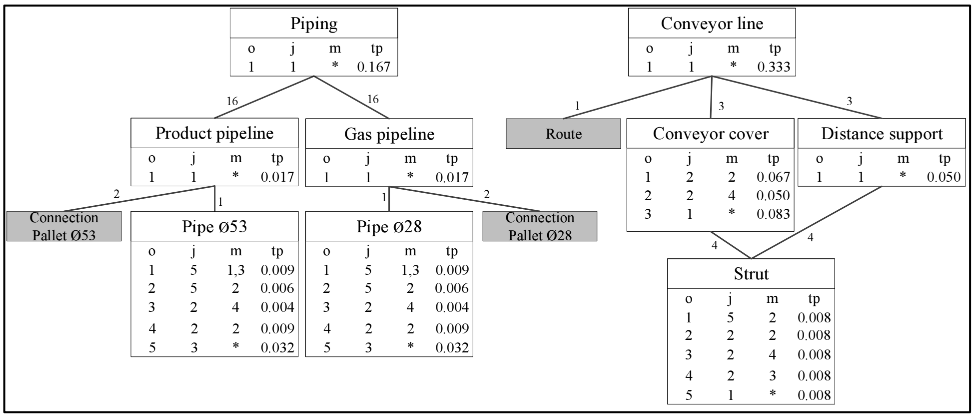

Figure 6: Gozintograph for product type 1 (piping) and product type 2 (conveyor line) – case study (2).

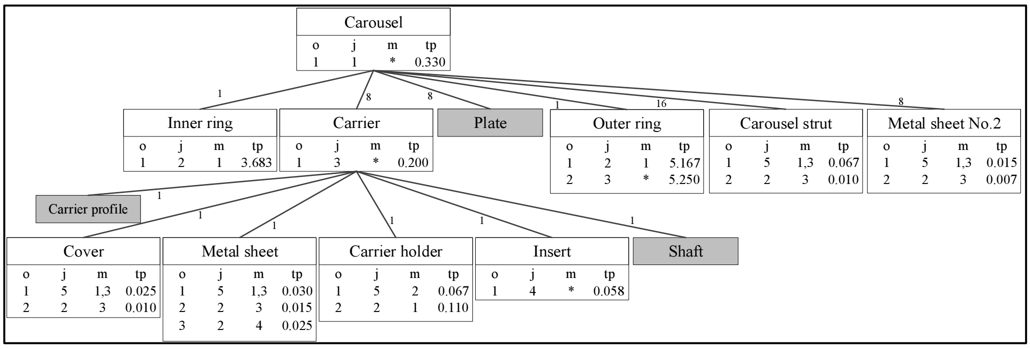

Figure 7: Gozintograph for product type 3 (carousel) – case study (2).

Case study (2) – Product type parameters

	f_k^P [in TU]	f_k^T [in TU]	f_k^E [in EU]	h_k [in MU]
Piping	180.78	180.78	13.70	50
Conveyor line	178.97	178.97	4.90	20
Carousel	132.42	186.30	443.82	130

Table 9: Product type parameters – case study (2).

Case study (2) – Capacity parameters

	b_t^P [in TU]	U_t^{max} [in TU]	b_t^T [in TU]	u_t [in MU]
per APP period	3520	880	5280	20

Table 10: Capacity parameters – case study (2).

Product type parameters are stated in Table 9. Table 10 shows the capacity parameters for case study (2). The initial inventory level is zero for all product types k ($I_{k0} = 0$). Customer demand for 360 periods was aggregated for APP. Demand quantities for each APP period is given in Table 11.

APP Period	1	2	3	4	5	6	7	8	9	10	11	12
Piping	13	9	6	6	4	11	12	4	9	7	5	16
Conveyor line	6	8	15	13	5	7	10	12	14	7	12	11
Carousel	3	1	2	3	3	1	1	2	3	1	3	1

Table 11: APP demand quantities – case study (2).

Aggregate production planning was carried out for twelve APP periods. Figure 8 shows inventory levels per period, personnel capacity usage as well as the energy consumption for the optimal solution of AGGRPLAN. Average energy consumption equals 1057 EU per APP period. Due to the peak in period 9 (2381 EU), difference between maximum and minimum energy usage per period is 1057 EU while deviation in energy usage per period equals 54%.

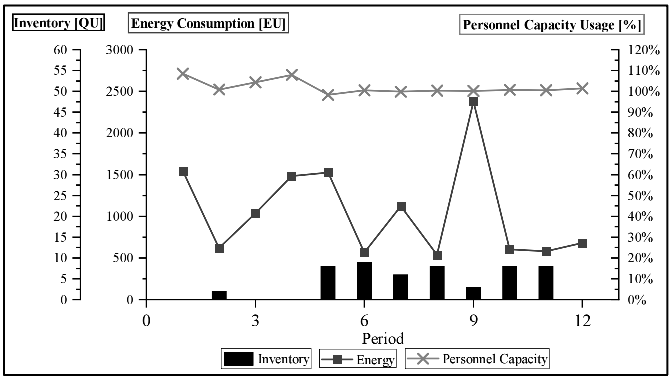

Figure 8: APP resulting in high deviation in energy consumption – case study (2).

In Period 9, five units of product type 3, carousels, are produced, leading to very high energy consumption in this period. Also, due to the changing demand structure along the planning horizon, in other periods energy consumption is varying while personnel capacity usage remains almost stable.

Case study (3) deals with the production of steel bridges and windtowers in a German steel working company in Northern Bavaria. Due to the long service life and individual layout of steel-fabricated bridges and windtowers, this case represents a make-to-order production approach.

27 employees work in production, producing steel parts for bridges and wind towers in a three-shift model. In total, seven machines are installed for polishing, cutting, edging, bending, welding, milling and coating the steel products. The shopfloor layout is shown in Figure 9.

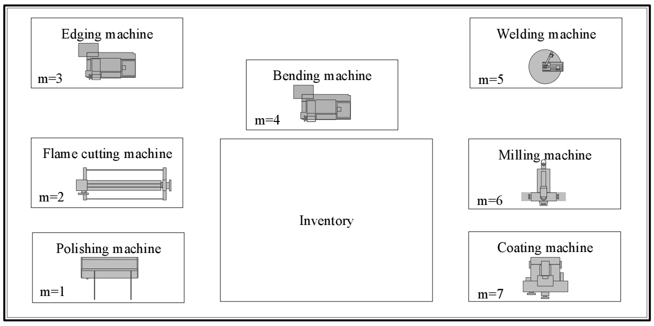

Figure 9: Shopfloor layout – case study (3).

Processing times are very long since both products are large in size and must meet specific safety regulations. The corresponding work schedules are given in Figure 10.

Bridge		
o	m	tp
1	1	48
2	2	120
3	3	48
4	5	144
5	6	120
6	7	96

Windtower		
o	m	tp
1	1	48
2	2	96
3	4	120
4	5	120
5	6	96
6	7	72

Figure 10: Work schedules for product types – case study (3).

Summed up net processing times as well as energy consumption for both product types are listed in Table 12.

Case study (3) – Net processing times [in TU] and energy consumption [in EU]	Personnel	Technical	Energy Consumption
Bridge	864.00	576.00	15720
Windtower	828.00	552.00	9696

Table 12: Net processing times [in TU] and energy consumption [in EU] – case study (3).

While net processing times are similar for both product types, the production of the bridge part is more energy-intensive in the processes of polishing, welding and milling. The reason for the higher energy consumption lays in the higher steel thickness of the bridge sections compared to the wind tower sections, resulting in a higher total energy consumption in the production of bridge parts.

Due to the long processing times of both product types, for aggregate production planning, the aggregation factor was increased to 90 simulation periods equal one APP period. Simulating 540 periods (equal to six APP periods in this case study) produced the following results for throughput time (Table 13).

Case study (3) – Throughput time [in time units]	Mean value	Deviation
Bridge	665.78	59.01
Windtower	607.11	48.37

Table 13: Throughput time [in TU] – case study (3).

For aggregate production planning, the following parameters in Tables 14 – 16 were used. The initial inventory level is zero for all product types k ($I_{k0} = 0$). Based on the varying demand quantities and the differences in energy consumption of bridges and windtowers, the optimal solution of AGGRPLAN leads to a fluctuating energy consumption per period, as shown in Figure 11. With a minimum energy consumption equal to 132072 EU and a maximum energy consumption equal to 192312 EU, a deviation of 14% occurs.

Case study (3) – Product type parameters	f_k^P [in TU]	f_k^T [in TU]	f_k^E [in EU]	h_k [in MU]
Bridge	998.67	665.78	15720	4860
Windtower	910.67	607.11	9696	7830

Table 14: Product type parameters – case study (3).

Case study (3) – Capacity parameters	b_t^P [in TU]	U_t^{max} [in TU]	b_t^T [in TU]	u_t [in MU]
per APP period	11520	2880	10080	40

Table 15: Capacity parameters – case study (3).

APP Period	1	2	3	4	5	6
Bridge	2	0	12	1	9	3
Windtower	13	13	2	12	3	11

Table 16: APP demand quantities – case study (3).

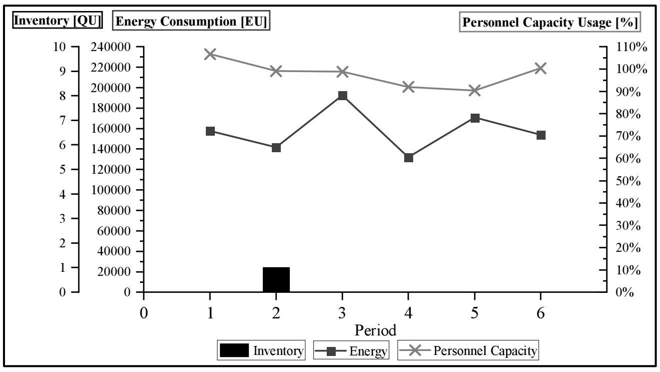

Figure 11: APP resulting in medium high deviation in energy consumption – case study (3).

CONCLUSION AND OUTLOOK

While energy-oriented production planning is widely known in short-term planning, existing literature lacks on mid-term planning that focus on energy consumption, especially on possible deviation in energy usage within a planning horizon.

Different product types having remarkable differences in energy consumption can be the case in production, as shown for manufacturing of two agricultural machines, three components for plant construction as well as for two steel parts, leading to high deviation in energy consumption per period as long as demand quantities and demand mix are varying. Those differences in energy consumption can occur in more companies and industries, as long as there is a product range that differs in the usage of energy-intensive processes and demand quantities are not constant. Thereby, such volatile energy consumption of a producing firm can result in planning uncertainty for energy suppliers and therefore in high costs for the energy supplier and its customers. By reducing such high deviation in energy consumption, both sides could benefit. The energy supplier gains

planning certainty and therefore could offer a favourable price to the energy demand side, leading to lower energy costs. However, when a producing firm reduces this deviation in energy consumption, one moves away from the former optimal production program in terms of costs, e.g. inventory costs and costs for additional capacity usage. Additionally, there can be situations, in which companies lack on the flexibility to change production quantities and corresponding energy consumption, as it might be the case for the make-to-order example in case study (3).
Therefore, future research needs to integrate energy consumption, respectively deviation in consumption, and its costs to find an optimal solution for both objectives, costs and deviation in energy consumption.

REFERENCES

Biel, K.; Glock, C.H. (2016): Systematic literature review of decision support models for energy-efficient production planning, in: Computers & Industrial Engineering, Vol. 101, pp. 243–259.

Chaturvedi, N.D. (2017): Minimizing energy consumption via multiple installations aggregate production planning, in: Clean Technologies and Environmental Policy, Vol. 19, No. 7, pp. 1977-1984.

Cheraghalikhani, A.; Khoshalhan, F.; Mokhtari, H. (2019): Aggregate production planning: A literature review and future research directions, in: International Journal of Industrial Engineering Computations, Vol. 10, No. 2, pp. 309-330.

Claus, T.; Herrmann, F.; Manitz, M. (2015): Produktionsplanung und -steuerung: Forschungsansätze, Methoden und deren Anwendungen, Springer, Berlin, Heidelberg.

Günther, H.O.; Tempelmeier, H. (2016): Produktion und Logistik: Supply Chain und Operations Management, BoD–Books on Demand.

Hax, A. C.; Meal, H.C. (1975): Hierarchical integration of production planning and scheduling, in M. A. Geisler (Ed.): Logistics. North Holland, Amsterdam, S. 53-69.

Kabelitz, S.; Streckfuß, U.; Gujjula, R. (2014): Einsatz von mathematischen Optimierungsverfahren zur energieorientierten Produktionsplanung, in: TBI2014.

Latifoğlu, Ç.; Belotti, P.; Snyder, L.V. (2013): Models for production planning under power interruptions, in: Naval Research Logistics (NRL), Vol. 60, No. 5, pp. 413-431.

Modarres, M.; Izadpanahi, E. (2016): Aggregate production planning by focusing on energy saving: A robust optimization approach, in: Journal of Cleaner Production, Vol. 133, pp. 1074-1085.

Nour, A.; Galal, N.M.; El-Kilany, K.S. (2017): Energy-Based Aggregate Production Planning For Porcelain Tableware Manufacturer in Egypt, in: Proceedings of the International Conference on Industrial Engineering and Operations Management, Rabat, Morocco.

Paterakis, N.G.; Erdinç, O.; Catalão, J.P. (2017): An overview of Demand Response: Key-elements and international experience, in: Renewable and Sustainable Energy Reviews, Vol. 69, pp. 871-891.

Paulus, M.; Borggrefe, F. (2011): The potential of demand-side management in energy-intensive industries for electricity markets in Germany, in: Applied Energy, Vol. 88, No. 2, pp. 432-441.

Rösch, M.; Lukas, M.; Schultz, C.; Braunreuther, S.; Reinhart, G. (2019): An approach towards a cost-based production control for energy flexibility, in: Procedia CIRP, Vol. 79, pp. 227-232.

Simon, R. (2017): Nachfrageseitige Flexibilitätsoptionen: Demand-Side-Management, Energiespeicher und Regelenergie, in: Matzen F., Tesch R. (Hrsg.): Industrielle Energiestrategie, Springer Gabler, Wiesbaden.

US Department of Energy (2006): Benefits of demand response in electricity markets and recommendations for achieving them – a report to the United States congress pursuant to section 1252 of the Energy Policy Act of 2005, February 2006.

AUTHOR BIOGRAPHIES

HAJO TERBRACK is a doctoral student at the Chair of Production Economy and Information Technology at the International Institute (IHI) Zittau, a central academic unit of Dresden Technical University. His e-mail address is: Hajo.Terbrack@mailbox.tu-dresden.de.

PROFESSOR DR. THORSTEN CLAUS holds the Chair of Production Economy and Information Technology at the International Institute (IHI) Zittau, a central academic unit of Dresden Technical University, and he is the director of the International Institute (IHI) Zittau. His e-mail address is: Thorsten.Claus@tu-dresden.de.

PROFESSOR DR. FRANK HERRMANN is Professor for Operative Production Planning and Control at the Ostbayerische Technische Hochschule Regensburg and he is the head of the Innovation and Competence Centre for Production Logistics and Factory Planning (IPF). His e-mail address is: Frank.Herrmann@oth-regensburg.de.