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NANOCOMPOSITES WITH POLYHEDRAL OLIGOMERIC SILSESQUIOXANE NANOFILLERS – CHARACTERIZATION OF MORPHOLOGY, THERMAL AND MECHANICAL PROPERTIES

Abstract
High-density polyethylene nanocomposites with hydroxy-hepta(*iso*-butyl)-octasilsesquioxane (POSS-(*i*-Bu)$_7$OH) and hydroxy-hepta(*iso*-octyl)-octasilsesquioxane (POSS-(*i*-Oct)$_7$OH) as nanofillers were prepared by melt blending. The morphological, thermal and mechanical properties as well as processability of obtained nanocomposites were characterized. POSS nanofillers were homogenously dispersed in polymeric matrix. High compatibility between nanofiller and polymer induced enhanced thermal stability, Charpy impact strength and melt flow rate for composite materials. POSS particles acted also as a nucleating agent for polyethylene crystallization in the nanocomposite.

Key words
nanocomposites, polyethylene, silsesquioxanes

Introduction

Nowadays, the design and development of new functional materials is one of the most intensively expanded research fields. Recently, special attention has been paid to the polymeric nanocomposites containing inorganic fillers. Such materials combine advantageous properties of organic polymers (e.g. processability, toughness, relatively low cost) and inorganic materials (high thermal and oxidative stability, durability), thus they are remarkably promising in various applications [1-4].

Recently, the polyhedral oligomeric silsesquioxanes (POSS) have gained particular popularity, among the all studied and used nanofillers. POSS are large and diverse family of compounds described with $(RSiO_{1.5})_n$ general formula, where R can be hydrogen or an organic group [5,6]. This class of materials can be considered as unique organic-inorganic hybrid compounds. Silsesquioxanes are consisted of a silicon-oxygen (siloxane) core, often in a cube form, and diverse functional substituents, which can be attached to this inorganic cage. This structure provides opportunities to modify the properties of POSS compounds in wide range [5-8].

POSS were successfully applied as nanofillers in preparation of interesting and useful polymeric nanocomposites, based inter alia on polyolefins, polyesters, polyamides and acrylates matrices [9-13]. In many cases, the introduction of POSS into polymers has a significant influence on their physical and chemical properties [10-12]. It was reported, that POSS particles can act as nucleating agents, plasticizers or fire retardants [14-18]. The application of POSS particles result also in the increase in the thermo-oxidative stability and use temperature, as well as in improving the mechanical, rheological and/or processability of polymeric materials [17-20].

In this work, we present the results of the studies on the effect of introduction hydroxy-hepta(*iso*-butyl)-octasilsesquioxane (POSS-(*i*-Bu)$_7$OH) and hydroxy-hepta(*iso*-octyl)-octasilsesquioxane (POSS-(*i*-Oct)$_7$OH) as nanofillers into high-density polyethylene (HDPE) matrix, on material's properties. The HDPE-based nanocomposite samples with 2 or 5 wt% POSS content were prepared by melt blending method. The morphological, thermal and mechanical properties, as well as processability of POSS-containing nanocomposites were investigated. It should be noted that in the case of polyolefin composites with POSS nanofillers, octasilsesquioxane derivatives with eight identical alkyl substituents at silicon-oxygen core have been mainly used [10-12]. Moreover, to the best of our knowledge, hydroxy-hepta(alkyl)-octasilsesquioxanes have not been applied as nanofillers in polyethylene composites, up to date.

Materials and methods

High-density polyethylene (HDPE) Purell GA 7760 (MFR = 18 g/10 min at 190 °C/2.16 kg) was provided by Basell Orlen Polyolefins. POSS-(*i*-Bu)$_7$OH (Fig. 1a) and POSS-(*i*-Oct)$_7$OH (Fig. 1b) nanofillers were prepared by Centre for Advanced Technologies AMU (Poznań, Poland) according to well-known literature method described by Caetano *et al.* [21]. All chemicals for the synthesis of POSS compounds were used as received from the supplier (Sigma-Aldrich) without any further purification.

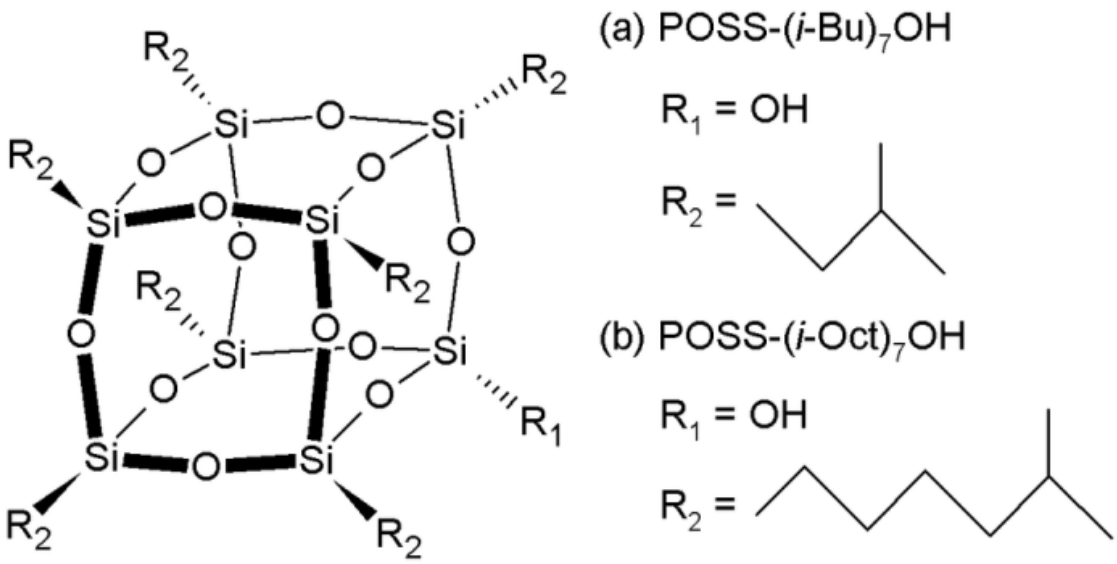

Fig. 1 Chemical structures of (a) POSS-(*i*-Bu)$_7$OH and (b) POSS-(*i*-Oct)$_7$OH nanofillers.
Source: Author's

The two-step process was used to prepare HDPE with POSS nanofiller. In the first step, the masterbatches containing 10 wt% of POSS were prepared in the HAAKE Polylab Reomixer (150 °C, 50 rpm, 15 min). In the second step, the HDPE/POSS nanocomposite samples were prepared by melt blending method using ZAMAK IM-15 laboratory conical twin screw extruder (155-170 °C, 100-200 rpm, 3 min) coupled with ZAMAK IMM-15 laboratory injection machine (165 °C, 6 MPa, 6 s). HDPE granulate and appriopriate masterbatch were mixed, at suitable weight ratios, to obtain nanocomposites containing 2 or 5 wt% of POSS-(*i*-Bu)$_7$OH or POSS-(*i*-Oct)$_7$OH.

The Fourier transform infrared spectroscopy (FTIR) was performed on a Thermo Scientific NICOLET 6700 spectrometer using attenuated total reflectance (ATR) technique by recording 32 scans in the 4000-650 cm^{-1} range.

The morphology of fractured surface of nanocomposite samples was observed by the scanning electron microscopy (SEM; Hitachi TM3000) equipped with the energy dispersive X-ray spectroscopy system (SEM/EDS). The samples were covered with thin layer of gold, before being examined, to provide their conductivity. SEM images were taken at the magnification of 2000× with the SEM operating voltage of 15 kV.

Thermal properties of nanocomposites were studied by the differential scanning calorimetry (DSC) method using a DSC1 Mettler Toledo device. Three successive runs (heating-cooling-heating) were performed at the 10 °C × min^{-1} rate under nitrogen flow with ca. 3-10 mg of samples. The presented data were taken from the cooling run (crystallization process) and second heating run (melting process). The crystallinity degree (X_c) was calculated from the ratio:

$$X_c = \frac{\Delta H_f}{w \cdot \Delta H_0} \cdot 100\% \quad (1)$$

where ΔH_f is the heat of fusion of the analyzed sample and ΔH_0 is the heat of fusion of the 100 % crystallinity sample (293 J × g^{-1} for HDPE [22]), and *w* is the mass fraction of polymer in the nanocomposite.

Thermogravimetric analyses (TGA) were performed on a TG/DSC1 Mettler Toledo device. The samples (3–10 mg) were put into alumina pans and heated under nitrogen from the room temperature to 500 °C at the 10 °C × min^{-1} rate.

The melt flow rate (MFR) values were measured according to ISO-1133-1:2011 (190 °C/2.16 kg) using a Zwick Aflow extrusion plastometer.

Charpy impact strength tests were performed using the Zwick HIT 50P machine according to PN-EN ISO 179-1. Notched bars were broken using a pendulum with the nominal energy of 0.5 J.

Results and discussion

ATR-FTIR studies

The presence of POSS nanofiller particles within the HDPE matrix was proved by ATR-FTIR technique. Figs 2a and 2b show ATR-FTIR spectra for neat HDPE and HDPE/POSS nanocomposites.

In the ATR-FTIR spectra of all samples, the absorbance bands with maximum intensivity at 2914 and 2850 cm^{-1} were observed, which were assigned to asymmetric and symmetric stretching vibrations of $–CH_2$ groups. The bands at 1472 and 1461 cm^{-1} from deformation and scissoring vibrations of $–CH_2$ groups were also visible [23,24]. However, in the case of HDPE/POSS nanocomposites, the band with maximum intensivity at 1120 cm^{-1}, which is associated with stretching vibrations of Si–O–Si bonds in the POSS cage, was also identified [25,26]. Moreover, the intensity of this band increased with the increasing content of the POSS nanofiller in composite materials, what confirmed the successful incorporation of POSS particles into polyethylene matrix.

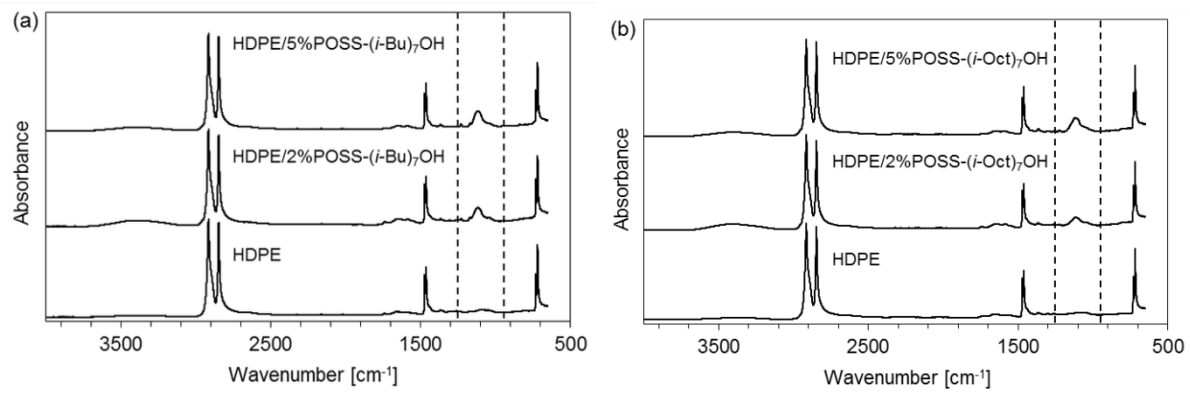

Fig. 2 ATR-FTIR spectra of neat HDPE and (a) HDPE/POSS-(*i*-Bu)$_7$OH as well as (b) HDPE/POSS-(*i*-Oct)$_7$OH nanocomposites.
Source: Author's

Morphology

The homogenous dispersion of nanofiller particles in polymeric matrix is one of the key factors determining the favorable and unique properties of nanocomposites. However, in the case of nanocomposites, the aggregation of nanofiller particles gains special significance, because contribute to an unsatisfactory reinforcing/improving effect of nanofiller [2, 27].

The dispersion of POSS particles in HDPE matrix was evaluated using SEM/EDS method. Fig. 3a-d show SEM micrographs and SEM-EDS Si-mapping micrographs of fracture surface of HDPE nanocomposites containing 2 and 5 wt% of POSS-(*i*-Bu)$_7$OH or POSS-(*i*-Oct)$_7$OH nanofiller. It was found that the POSS particles were uniformly dispersed throughout the polymer matrix, regardless to the kind of POSS nanofiller used. Moreover, no aggregates of nanofillers were observed even at higher content of POSS in nanocomposite materials. It could be explained by favorable interactions between the POSS nanofiller particles and polymer. Similar observations were reported in the case of polypropylene composites with POSS nanofillers which contained *iso*-butyl or *iso*-octyl groups attached to the silicon-oxygen cage [14, 19] as well as for polyethylene composites with *n*-hexadecyl-substituted POSS [20]. Thus, it could be concluded that the presence of hydroxyl group in the POSS molecule does not worsen the dispersion of POSS in HDPE matrix.

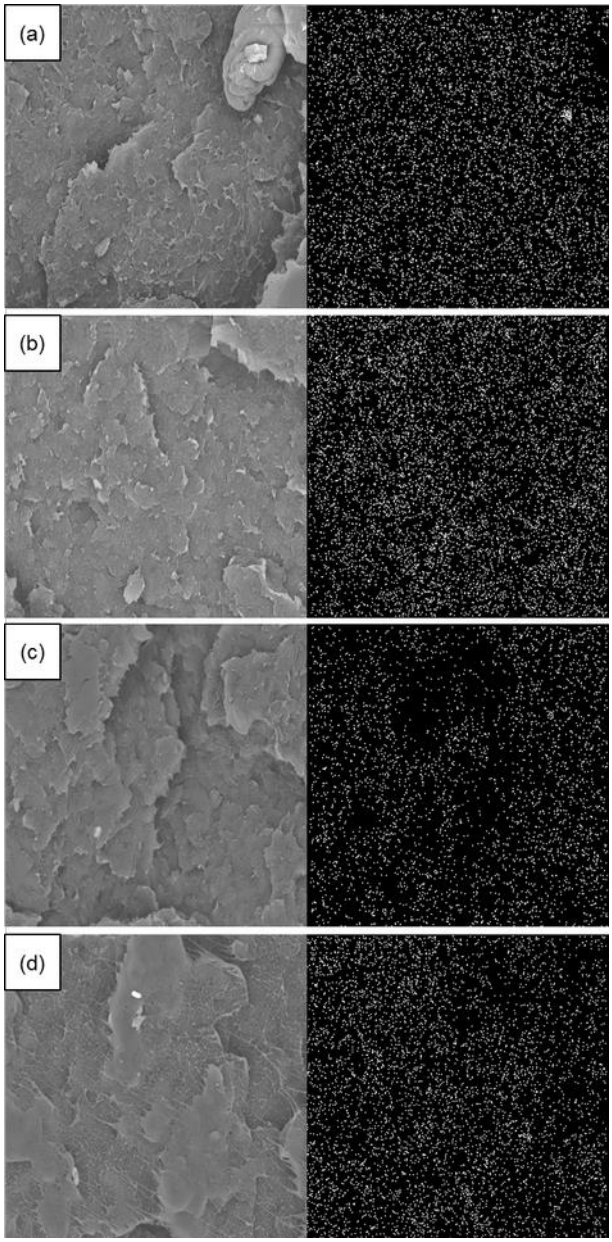

Fig. 3 SEM micrographs (left column) and SEM/EDS Si-mapping micrographs (right column) for the (a) HDPE/2%POSS-(*i*-Bu)$_7$OH, (b) HDPE/5%POSS-(*i*-Bu)$_7$OH, (c) HDPE/2%POSS-(*i*-Oct)$_7$OH and (d) HDPE/5%POSS-(*i*-Oct)$_7$OH nanocomposites. *Source: Author's*

Crystallization and melting behavior studies

The introduction of POSS particles into polyolefin matrices may improve crystallization and melting behavior of polymer, thus POSS can act as nucleating agent. Moreover, in the case of POSS-containing nanocomposites, the structure and the amount of applied POSS nanofillers have a great influence on the melting and crystallization process of polymeric matrices [14,15].

In this study, the influence of addition of POSS-(*i*-Bu)$_7$OH and POSS-(*i*-Oct)$_7$OH nanofillers particles on the crystallization and melting characteristic of HDPE matrix was evaluated by DSC analysis. The DSC results, such as crystallization temperature (T_c), melting temperature (T_m) and crystallization degree (X_c) for neat HDPE and HDPE/POSS nanocomposite samples are shown in Tab. 1. It was found, that introduction of POSS particles into HDPE matrix resulted in a slight decrease of T_c and T_m, regardless to the type and amount of applied nanofiller. Similar changes were also observed for other polyethylene composites with POSS nanofillers as reported in previous works [28-31]. Worth mentioning is that *Perrin et al* [28] suggested that small amounts of POSS

nanofiller does not significantly influence the crystalline structure of PE, regardless to the structure of substituents in POSS molecules.

In turn, values of X_c increased with increasing POSS content in composite materials. Moreover, somewhat higher increase of crystallinity degree values was observed in the case of nanocomposites with the POSS-(*i*-Bu)$_7$OH particles, which contain shorter (*iso*-butyl) substituents attached to the POSS cage, in comparison to the materials with POSS-(*i*-Oct)$_7$OH nanofiller (with *iso*-octyl substituents). It may be assumed that the arrangement of high-density polyethylene polymer chains in the presence of POSS-(*i*-Bu)$_7$OH and POSS-(*i*-Oct)$_7$OH nanofillers was more ordered. This observation is in agreement with results described in the literature [28,31] where the slight increase in the polymer crystallinity after addition of POSS particles was also demonstrated.

Tab. 1 DSC results of neat HDPE and HDPE/POSS nanocomposites.

Sample	T_c [°C]	T_m [°C]	X_c [%]
HDPE	118.4	132.1	73.9
HDPE/2%POSS-(*i*-Bu)$_7$OH	118.0	131.7	74.7
HDPE/5%POSS-(*i*-Bu)$_7$OH	117.7	131.5	75.6
HDPE/2%POSS-(*i*-Oct)$_7$OH	118.1	131.4	72.7
HDPE/5%POSS-(*i*-Oct)$_7$OH	118.2	131.4	75.0

Source: Author's

Thermal stability studies

The type and amount of POSS nanofiller introduced into polymer matrix strongly affect the thermal stability of the nanocomposites obtained. This can be explained by the high rigidity and thermal stability of silicon-oxygen structure of POSS core [9]. It was determined that during the thermal decomposition of POSS-containing nanocomposites, a silica-like residues, which are produced on the surface of material, can act as protective barrier [28,32].

Fig. 4 shows the values of the maximum mass loss rate temperature (T_{max}), which defines the temperature at which thermal decomposition of sample take place with the highest rate [33]. It was found that introduction of 2 wt% of POSS nanofillers into HDPE matrix improved the thermal stability of nanocomposites, irrespective to the kind of nanofiller applied. However, further increase in content of POSS nanofillers led to slight decrease of T_{max} values. Interestingly, HDPE/POSS-(*i*-Oct)$_7$OH nanocomposites had higher thermal stability, than HDPE/POSS-(*i*-Bu)$_7$OH nanocomposites. It should be noted that the lack of significant changes of thermal stability (in nitrogen atmosphere) after incorporation of POSS particles into polyethylene matrix was also reported in literature [28,32].

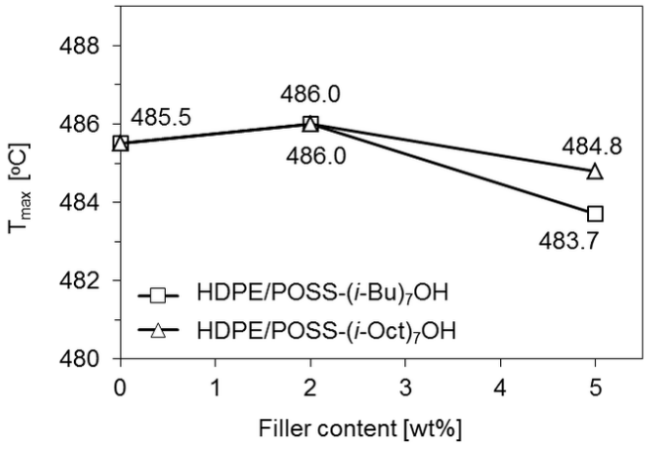

Fig. 4 The maximum mass loss rate temperatures (T_{max}) of HDPE and HDPE/POSS nanocomposites.
Source: Author's

MFR studies

The ease of operation, low cost and repeatability of the results make the MFR an important parameter that is widely used in the industry [34]. Moreover, the determination of MFR values gives valuable information about the materials processability and allows the estimation of changes in rheological properties, due to e.g. changes in the material's microstructure [34,35].

Fig. 5 shows the MFR values of neat HDPE and HDPE/POSS nanocomposites. The introduction of POSS particles into HDPE matrix caused increase in MFR values, in comparison with neat polymer. Moreover, the MFR values increased with the increasing content of nanofiller. It should be noted that the addition of POSS-(*i*-Oct)$_7$OH with *iso*-octyl substituents on silicon-oxygen core to the HDPE resulted in larger improvement of MFR, in comparison with HDPE/POSS-(*i*-Bu)$_7$OH nanocomposites. It could be explained by higher compatibility between POSS-(*i*-Oct)$_7$OH molecules containing longer *iso*-octyl substituents with HDPE, than POSS-(*i*-Bu)$_7$OH with shorter *iso*-butyl substituents attached to the POSS core. Thus, this indicates that POSS molecules with long alkyl substituents attached to the POSS cage could act more efficiently as plasticizers. This is probably caused by disengagement in the polymer chain packing in presence of POSS nanofiller particles, what affects the microstructure of nanocomposite materials obtained. It should be emphasized that *Huang et al* [30] and *Joshi et al* [36] also indicated on the formation of free volumes in the melt after introduction POSS particles into polyethylene matrix.

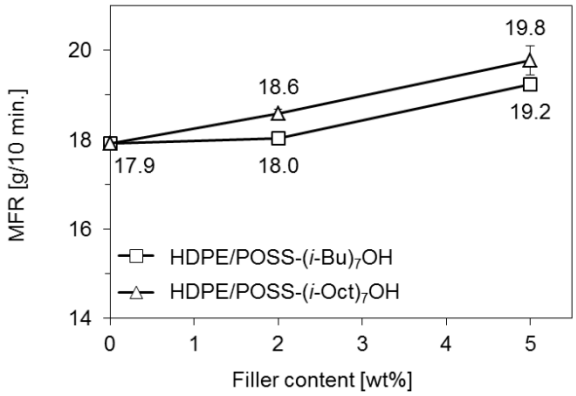

Fig. 5 MFR values of HDPE and HDPE/POSS nanocomposites.
Source: Author's

Charpy impact strength

Fig. 6 shows the values of Charpy impact strength as a function of POSS content. It was observed that the increasing content of POSS-(*i*-Oct)$_7$OH in HDPE matrix resulted in clear improvement of this parameter. In turn, addition of POSS-(*i*-Bu)$_7$OH particles caused only slight enhancement of impact strength of HDPE/ POSS-(*i*-Bu)$_7$OH nanocomposite. The better results obtained in Charpy impact strength tests in the case of HDPE/POSS-(*i*-Oct)$_7$OH nanocomposites confirm more uniform dispersion of POSS-(*i*-Oct)$_7$OH particles in HDPE and their high compatibility with HDPE polymer chains.

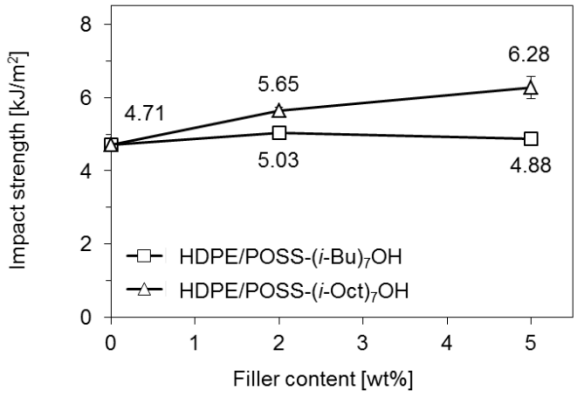

Fig. 6 Charpy impact strength values of HDPE and HDPE/POSS nanocomposites.
Source: Author's

Conclusions

The effect of introduction of POSS-(*i*-Bu)$_7$OH and POSS-(*i*-Oct)$_7$OH particles as nanofillers into HDPE matrix on morphology, thermal and mechanical properties as well as processability of obtained nanocomposites was investigated. The influence of the structure and wt% content of the POSS nanofillers in the nanocomposites was also studied.

The application of POSS as nanofillers for polymer nanocomposites give opportunities to develop the interesting and unique materials, because material's properties could be modified by structural control of POSS derivatives used. The presence of POSS particles in HDPE/POSS nanocomposites was proved by ATR-FTIR spectra. Moreover, it was found that the POSS particles were uniformly dispersed in polyethylene matrix, regardless to the kind and wt% content of nanofillers, as determined by SEM/EDS analysis. The structure of the substituents attached to the POSS cage (*iso*-butyl or *iso*-octyl) had a significant influence on the properties of HDPE/POSS nanocomposites. Interestingly, crystallization and melting behaviors of prepared nanocomposites were almost unchanged, in comparison to the neat HDPE. However, X_c values were increased, especially in the case of HDPE/POSS-(*i*-Bu)$_7$OH nanocomposites. This could prove that POSS with short alkyl substituents (such as POSS-(*i*-Bu)$_7$OH) could act as nucleating agents which contributed to the increase in the polymer chains arrangement. The thermal stability of POSS-containing materials was slightly improved after introduction of 2 wt% of POSS nanofillers. Somewhat higher T_{max} values were observed for materials with POSS-(*i*-Oct)$_7$OH than in the case of HDPE/POSS-(*i*-Bu)$_7$OH. This is the result of better compatibility between HDPE and POSS containing *iso*-octyl substituents. HDPE-based nanocomposites with POSS were characterized by higher MFR values, and thus by better processability, than neat polymer. Moreover, the increasing POSS wt% content resulted in increase of MFR values for nanocomposites. Such behavior may be related to the POSS role as plasticizers in HDPE. Mechanical properties determined by Charpy impact strength were improved after introduction of POSS nanofillers into HDPE and better results were obtained in the case of HDPE/POSS-(*i*-Oct)$_7$OH nanocomposites.

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THE VALUE OF CROWDSOURCING FOR CREATIVE CLUSTERS DEVELOPMENT

Abstract
The article consists of three integral parts. It characterises the essence of the functioning of creative clusters, the concept of open innovation and crowdsourcing strategic dimension. Considerations presented in the article are focused on the importance of crowdsourcing in the development of creative clusters. The problem of using crowdsourcing to solve complex problems can be evaluated with multiple levels and multiple perspectives. The authors emphasise that this model of communication between cluster members and external stakeholders allows the use of internal and external resources of creativity in the process of co-creation of positive changes, including innovations (e.g. entrepreneurial solutions to local and global new challenges). They indicate that the implementation of the crowdsourcing in creative clusters can have both, a commercial dimension, where new business projects are the result of the transfer of knowledge, and a non-commercial one, for instance, a wider use of this concept in the development of creative spaces. It was stressed that innovativeness is one of the attributes of entrepreneurial orientation of clusters. Moreover, the key barriers to development of open innovation within a cluster environment are different problems related to intellectual property. The article is based on theoretical research (literature review) and on desk research. Considerations contained herein are conceptual and provide a starting point for further research on the impact of crowdsourcing on the open innovation process within creative clusters.

Keywords: cluster, management, creativity, innovation, crowdsourcing, development

Introduction

Creative clusters, that gather together on its territory cooperating entities from creative sector and related industries, provide a priori suitable environment for the development of open innovation and the effective implementation of crowdfunding. It is worth stressing that within internal environments, clusters operate active internal prosumers – cluster members who are not only consumers of creative products, but also willingly and vigorously co-create them. However, it is necessary to provide professional cluster management for implementation of innovative activities in joint projects to efficiently exploit the strategic potential of creative clusters and ensure dynamic development of cluster community.

The diversity of problems faced by cluster organisations requires different approach to solve them. Currently, one of the strategic challenges in managing creative cluster is the problem of using the wisdom of crowds (i.e. individuals and entities with a common interest, prosumers, internal and external stakeholders) in the development of these structures, including open innovation development. In this process the information and communication technologies (ICT) have strategic significance, because they offer support for R&D activities in clusters. This kind of contemporary management challenge led to five related research questions:

- why creative cluster is an open space for open innovation?
- what are the key barriers to the development of open innovation in clusters?
- why cluster members use their intellectual property and human capital within common cluster projects, although they know that final benefits are important for their competitors?
- what is the significance of crowdsourcing for the development of open innovation within creative clusters?
- why crowdsourcing is a valuable tool for creative cluster development?

The choice of this research problem was the effect of the scarcity of research in this field (particularly in the area of management sciences). Scientific considerations, based on selected results of theoretical and desk research, are meant to help to fulfill this gap. These considerations are the basis for further research on propensity of members of the Polish creative clusters in innovation development in using open innovation model based on crowdsourcing platforms, the scale of the phenomenon or the relationship between the intensity of open innovation and clusters individual attributes. For a more comprehensive understanding of how these platforms (as a form of information and communications technology) support open innovation, this needs to be broadened to include key factors that constrain the adoption of open innovation in clusters and those clusters members who do not want extensive use of technologies. Further work is needed to explore in detail the crowdsourcing approaches and processes used by cluster members to achieve specific outcomes. Thus, prospects for research on the attractiveness of crowdsourcing within creative clusters are good.

Creative clusters: open space for innovations

Clustering is still a crucial concept for developing industries, including cultural and creative industries. Clusters evolve basing on geographical proximity, develop over time and space, which boosts competition and collaboration resulting in innovation process, and potentially creates greater economic benefits through higher productivity, better knowledge management, and entrepreneurial attitudes [1, p. 553].

Creative cluster – as a type of cluster structure based on geographic concentrations of interconnected people or companies to create new product – is becoming increasingly an important component of knowledge-based economies [1, p. 552]. Usually, it is largely characterised by social networks that integrate creative firms and individuals together in a delimited geographic space (social and creative milieu). Therefore, creative clusters can be understood as [2, p. 26-27; 3, p. 13; 4, p. 9; 5, p. 99; 6, p. 552; 7, p. 3]:

- a geographically proximate group of interconnected companies and associated institutions (e.g. R+D sector, local government, non-profit organisations), in a creative sector, linked by commonalities and complementarities;
- a specific kind of cluster connected with the creative sector;
- a linked group of creative industries, firms and/or cultural activities spatially concentrated;
- an organisation of different and interconnected partners that produce complementary creative goods and are usually produced through the exploitation of a value chain within creative sector where common inputs, specific skills, and technologies are used;
- an overlap area between cultural and commercial activities;
- cooperation and competition (coopetition) between organisations which deal with the supply of goods and services that contain a substantial element of artistic, imaginative or intellectual effort and play a vital role in sustaining cultural activities;
- activities related to the creation, production and/or distribution of creative goods and services as well as with the integration of creative elements into wider processes and other sectors;
- broader range of activities which include the cultural industries as well as all cultural or artistic production, whether live or produced as an individual unit;
- primarily formed in various creative environments, including institutions of high culture, e.g. museums, concert halls, opera houses and institutions representing popular culture, e.g. theater, cinema, and other entities involved in the wider arts and entertainment activities – as well as private stakeholders in architecture, advertising, publishing and other closely related industries;
- a type of urban quarter that has a high concentration of cultural activities and creative industry companies with on-site networks that create added value.

The concept of creative clusters may be interpreted differently due to the fact, among others, that such clusters are often created by cultural sector entities. On one hand, creative clusters include the so-called kernel of creativity (cultural heritage, visual and stage arts) and, on the other, one specific sectors of culture such as film, music, books, newspapers, radio and TV and the creative industries, e.g. computer games, software, design, fashion, architecture and advertising [8, p. 11]. According to A. Klasik, creative clusters consist of companies, non-profit organisations, cultural and research institutions and special meeting places (such as science parks, cultural centers and media centers) that stimulate ideas exchange between individual artists and scientists. In these clusters there are produced and consumed products based on intellectual property (e.g. patent, new technology, trademark, brand, copyright work, among others) [9, p. 15]. Thus, they require extensive coordination and active participation of local authorities. It is especially important at the stage of

linking local actors from the creative sector and aimed at using their intellectual capital (including relational capital) in the creation of new ideas, products and services, valuable for the ultimate purchaser.

According to J. Foord [5, p. 111], if the aim is to facilitate creative place, then more attention needs to be paid to the particularities of locality. Today, the creativity may be found everywhere, but perhaps not all the localities can become "creative places" with the competitive advantages. This type of spaces and environment stimulate the creativity of individuals and teams by a wide range of positive incentives arise in the urban, commercial and / or public space. Entities located in creative clusters systematically encourage cross-linking, active use of a wide range of services and creative products, enabling the co-creation of new creative products. The creative clusters tend to concentrate in the metropolitan areas (large urban zones) and are particularly important in the largest ones [10, p. 24]. Location of creative companies in creative clusters is not accidental. It is the result of rational decision of the owners of these companies, who perceive the cluster as an attractive space for further growth and development. Many companies in the creative sector come into direct interaction with customers, playing an increasingly important role in creating innovation and accelerating growth of other sectors [11, p. 20].

The research report "Creative clusters and innovation: putting creativity on the map" is the most ambitious attempt to map the UK's creative clusters, showing where they are, which sectors form them, and what their role is in the systems of innovation where they are embedded. Creative clusters play a strategic role in the dynamics of innovation of the places where they are located. High levels of innovation in the creative industries and creative clusters make them a potential source of innovation spillovers into other sectors. The study shows the existence of links between creative businesses and the wider Regional Innovation System. Moreover, very often, interactions between the creative industries and other sectors in their vicinity have an innovation rationale. The research also shows that the creative industries are more innovative than many other high-innovation sectors, for example professional and business services. What is more, the creative industries provide a disproportionate number of the innovative businesses in most parts of the country [12, p. 4,42].

Published research findings by W. Yu, J. Hong, Y. Zhu, D. Marinova, and X. Guo about the impacts of creative industries cluster (CIC) on regional innovation and economic growth in China also showed that creative clusters are the best space for innovative companies' development, or this kind structure is more innovative than other industrial clusters. Their research has examined the role of China's creative industries cluster in region innovation and value added in other sectors. They distinguish two kinds of regional innovation effects (i.e., upstream effect): novelty-oriented and efficiency-oriented innovation, and they investigate two sectors of valued added effects (i.e., downstream effect): traditional and high technology industries. Given this role of the CIC in regional innovation and economic growth, innovation policy-makers should further establish more CIC zones and advance the contribution on the wider regional innovation system construction. They argue that the Chinese government should pay much more attention to the concentration of creative industries at regional levels because regional CIC is a significant factor for regional novelty and efficiency improvement. To develop more CIC zones may be an opportunity to improve regional novelty innovation and efficiency innovation for China's economic growth transition, from extensive economic growth to an increase driven by innovation impetus [13, p. 345].

Creative cluster, as well as each organisation, has a recognisable life cycle. This cycle refers to the sequence of various stages, which immediately follow each other in a logical manner. Often, the development of creative clusters concerns five phases: embryonic, aspirational - entrepreneurial initiative, emergent - dynamic development, mature, decline or transformation (Tab. 1). In order to ensure the sustainability of creative cluster and taking into account its social and technological base, it is necessary to stimulate and facilitate innovative activity that will involve all members of the cluster.

Creative clusters are not conventional business clusters and additional factors are critical to their development and form (especially the role of publicly funded arts and cultural institutions) [5, p. 99]. The potential of certain locations to support the growth of the creative clusters depends on the different dimensions, such as [14, p. 11]:

- hard infrastructure: local availability of business spaces, wealth of the local population or tourism and/or transport infrastructure of a place;
- soft infrastructure: soft, idiosyncratic reasons such as networks, a specific image or identity of the place, the presence of traditions;

- governance: policy strategies and initiatives, engagement of the creative industries with various policy arenas such as local regeneration, economic development, social inclusion, etc.;
- markets: the creative industries operate in very fast changing markets where uncertainty of demand and interaction with clients and customers are something permanent.

Table 1. Creative cluster development

Development level	Characteristic
embryonic - dependent - identification	▪ a group of regional entities (enterprises, scientific and administration units) which identify a possibility of cooperation within the cluster ▪ meetings with initiators and experts, presentation of benefits from cooperation, encouraging the assessment of own competences versus ▪ competition and potential cooperation partners ▪ creative enterprises developed as a direct result of public sector intervention through business support, infrastructure development for cultural consumption and finance to SME/micro creative enterprises ▪ public subsidy required to sustain the cluster ▪ limited and underdeveloped local markets
aspirational - entrepreneurial initiative	▪ some independent creative enterprises and/or privatised former public sector cultural enterprises in place but limited in scale and scope ▪ underdeveloped local markets and limited consumption infrastructure ▪ high levels of public and institutional promotional activity ▪ development by social capital ▪ the emotional engagement of cluster's participants in cluster cooperation ▪ the growth influenced by benefit collocation and exogenous growth ▪ new firms or actor join the cluster ▪ formalised institution of collaboration
emergent - dynamic development	▪ initiated by growing number and scale of creative enterprises with infrastructural investment from the public sector ▪ developing local and regional markets with visible cultural consumption ▪ economic agglomeration plays an important role in encouraging growth and transformation of cluster structure ▪ innovations emerge increasingly as a result of inter-organisational cooperation ▪ focus on internationalisation
mature	▪ the critical mass established ▪ strong relationships of cluster members with other clusters ▪ achieving operational excellence, independent diagnosis of market trends, preparing strategies and increasing competences in strategic management required ▪ development by cluster governance ▪ led by established large-scale creative firms in specific industries with established sub-contracting linkages and highly developed national and international markets ▪ cluster develops its structures and social responsibility, however, with decreasing its primary dynamics ▪ the process of cluster maturing is connected with exhaustion of development possibilities in given shape of cluster ▪ arms-length public intervention ▪ low cluster flexibility - progressive loss of cluster competitiveness
decline or transformation	▪ transformation to new cluster specialisation ▪ new ideas are the beginning of new networks and structures which results in new emergent cluster ▪ new model of cluster management

Source: Authors', based on [5, p. 100; 15, p. 357-360; 16, p. 201-207].

Currently, from an economical point of view, clusters can be seen not only as an example of cooperation through informal and formal economies of scale, spreading risk in R&D and information sharing via socio-economic networks, but also as reactive anti-establishment action (avant-garde, artists' squats), defensive necessity, resisting control from licensing authorities, global firms, guilds and artistic and political mainstream [17, p. 34]. Therefore, the concept of creative cluster can be applied as a strategy for urban regeneration, policies formulation and execution, protection of local creative industry in the context of increased competition from the other regions, and creative districts, quarters with a "cool" subculture for freelancers and SMEs [18, p. 45]. The strategic aims of creative clusters are different from traditional business or industrial clusters and have also social objectives such as inclusion and cultural development [5, p. 99].

Successful creative cluster development can be a key to regional competitive advantage. Nowadays, the challenge is how to ensure the continued success of existing clusters and enhance the growth of emergent clusters [6, p. 550]. The rationale for creative industry clusters is mixing characteristics of culture production and culture consumption centers and the benefits of clustering/agglomeration effects [4, p. 10]. According to S. Olko creative clusters are the basis of resources, creative skills and development of innovation in the region. Often, they also support local and regional identity, increasing investment and tourism attractiveness of the territory [19, p. 176]. This type of clusters is often seen as exemplary in terms of identifying historical memory, local identity and authenticity that might even incorporate into the content or branding of their business [20, p. 124]. They can also contribute to [21, p. 76]:

- increase of public participation in culture and other creative industries,
- increase in sales and licensing of copyright works,
- increase of availability of creative public spaces,
- increase in importance and popularity of the cluster location,
- new joint projects in field of design, including industry design,
- active participation of cluster members in international projects,
- better attention to artistic and intellectual uniqueness.

Moreover, these clusters serve different purposes in region, for example [21, p. 78]:

- can be an area for shaping pro-innovative attitudes of key stakeholders,
- can assist other clusters or single organisations (public, social and commercial) in development, creation and commercialisation of innovations,
- can be used as an accelerator of innovation processes in the economy thanks to the introduction of innovations at various stages of value chain,
- can form a network for talent development (knowledge workers) for proximal and distal environment (including international).

The creative clusters are believed to provide an environment where there can be minimised direct and indirect costs associated with open strategies (such as contractual, knowledge search costs, transmission costs), the uncertainty and risk in collaborative relationships and possible conflicts between inbound and outbound knowledge flows [22, p. 108]. Only active and strong creative clusters provide benefits, not only to its members, but also to the external environment (spillover effect). The positive influence of this type of clusters for the process of development of knowledge and innovations helps the creation of the knowledge-based economy and information society. For this reason, the synergy effects that can be created in the environment of these type of clusters contribute to them being considered as local and regional instruments of socio-economic development.

Open innovation: the need or challenge within the creative cluster development?

Today, clusters operate under turbulent environment. Particularly dynamic changes that take place in the field of computerisation, cyber security, development of digital technologies, network communication, Web 2.0 and other technological innovations are important for their development. These changes, acting as a determinant of knowledge-based economy, accelerate the implementation of the principles of Open Access model in the process of development of science and R&D. Contemporarily, the norms of open science promote rapid diffusion of the latest knowledge and invite broader stakeholders to participate in the discovery of new knowledge and innovations [23, p. 3].

The concept of open innovation is based on sources of knowledge developed in the scope of organisation and environment (entrepreneurial or entrepreneurship ecosystem). It is especially important at cluster level where internal research and knowledge or external sources of innovation are especially active, creating a space where high technology meets creative processes with an aim to develop new products. Contemporary approach to open innovation may be pursued in many ways, for instance [7, p. 5; 22, p. 86; 23, p. 12; 24, p. 15; 25, p. 174-175]:

- theory where generation of innovative outputs is facilitated by more openness towards external knowledge sources,
- the notion that innovations are not always inspired and developed entirely within a single firm,
- innovation collaboration or knowledge flows across organisational boundaries,
- processes which combine internal and external ideas together into platforms, architectures and systems,
- organisational form of knowledge acquisition and exploitation in a given time horizon,
- broad and effective engagement and participation in the innovation process,
- number of partners, from dyadic partnerships to networks and typologies of partners, from traditional supply chain relationship to collaboration with universities, technical service companies, competitors and firms operating in different industries,
- phases of the innovation process that exploit external and internal sources,
- the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation, respectively,
- model which explain how ideas and innovations are to be transferred across the organisational boundaries in order to create value and new income streams.

Considering the results of studies and analysis linked to open innovation in clusters, it is shown that despite the higher levels of social capital and quality of business-to-business cooperation, there are still many barriers to implement this concept efficiently. Among the most frequently mentioned obstacles, the problem of intellectual property is still the major one (Tab. 2). Key barriers to adoption of open innovation are situated on three different levels [26, p. 11]:

- internal factors at company level (for instance, R&D intensity and availability of surplus technologies),
- innovation system level (for instance, influence of innovation policies and public funding on firm's involvement in open innovation processes),
- cultural level (certain features of national and organisational culture creating an attitude towards the use of open innovation practices within the company).

Table 2. Key factors that constrains the adoption of open innovation in clusters

Areas	Barriers to the development of open innovation
Absorption of knowledge	▪ lack of financial resources ▪ time constraints ▪ lack of internal skills ▪ differences in organisational culture with external partners ▪ IP management problems ▪ distant location of external partners ▪ lack of trust in external partners
spin-offs development	▪ lack of financial resources or logistical conditions ▪ high degree of specialisation / lack initiative of workers ▪ unawareness of the advantages associated with the creation of spin-offs ▪ lack of information about the kind of support that can be given ▪ fear of competitive threat
support for ideas development	▪ lack of financial and/or logistical resources to support ideas ▪ limitation of working hours ▪ preference for collaboration with external entities to capture new ideas and suggestions for improvement and lack of internal skills to take advantage of the ideas proposed
IP strategy	▪ unawareness of the advantages and/or forms of IP protection ▪ difficulty in demonstrating the novelty of the invention ▪ costs associated with the registration/application for IP protection ▪ costs associated with maintenance of IP rights

Areas	Barriers to the development of open innovation
	▪ copy fear (by competitors) - fear of competitive threat ▪ costs associated with IP litigation ▪ high cost of acquisition of external IP ▪ lack of information on the forms of IP sale to other entities and licensing advantages (in the case of SMEs) ▪ problems with the ownership of IP rights within partnership projects ▪ disagreement with external partners in the form of use of IP
funded projects developed with external entities	▪ coordination problems (many partners involved) ▪ difficulty in project management and sharing results with partners ▪ IP protection conflicts ▪ skills gap between the partners involved

Source: Authors', based on [28, p. 28; 29, p. 157].

In order to eliminate this type of barriers, it is important to organise discussions within the cluster about protection of intellectual and industrial property. It is necessary to explain how can use intellectual and industrial property assets in the cluster in the most efficient and effective way that at the same time comply with the law. Of course, there is no unique answer, because in one case may be more valuable a system of licensing or patents and in the other - free revealing. Often, some cluster members have a negative attitude towards patenting due to the inadequacy of the tempo of technological change in relation to longevity of the safeguard procedures. They propose a more radical solution like open source, especially in field of software [27, p. 19]. The complexity of the structure of creative clusters, causes that collective management organisations (as key stakeholders) in solving potential problems related to copyrights they can be very helpful.

According to H. Chesbrough [23, p. 12], the open innovation model assumes that firms or innovating institutions can and should use external and internal ideas, as well as external and internal paths to market, as they look to advance their innovations. Open innovation models highlight the importance of using a broad range of knowledge sources for a firm's innovation and invention activities, including customers, rivals, academics and firms from unrelated industries while simultaneously using creative methods to exploit the firm's intellectual property (IP) [30, p. 319]. Active knowledge management is important because overly strong protection of IP, or prematurely assigning IP rights at early stages of scientific inquiry, can stifle innovation rather than advance it [23, p. 3].

H. Huang and J. Rice [22, p. 108], based on their own research, argue that the open innovation model could be effectively implemented and actively encouraged within regional clusters to drive regional innovation performance and create a collaborative arrangement among firms in a competitive local environment. Under such conditions, local entrepreneurs and entrepreneurial universities in regional clusters (e.g. creative clusters) also are more likely to take advantage of external knowledge sources to create successfully innovative products and start-ups. Most of the key benefits proposed by researchers within open innovation model are based on the ideas of interdependence, trust and mutual reciprocity that facilitate knowledge sharing, transfer and benefits of appropriation [22, p. 108].

The model of open innovation is somehow included in the clusters nature, including creative clusters. Nowadays, for many clusters (including those based on innovations), the open innovation model seems to be not only a need, but also a necessity. The main attributes of open innovation are co-creation, knowledge sharing between partners and their interrelations. The effectiveness of these processes depends both on the quality of partnership in the cluster, as well as the quality of its information and communication technologies (ICT), including tools such as crowdsourcing platforms.

Strategic dimensions of crowdsourcing for creative clusters

Today, the concept of crowdsourcing has strategic potential for creative cluster development and relationship management with key stakeholders. Crowdsourcing is a narrower term compared to open innovation or co-creation innovations, as the latter two encompass any inflows or outflows of innovation in any way. It is focuses more on inflows from efforts of single individuals or small groups [31, p. 73]. Moreover, crowdsourcing does not necessarily capture profit-oriented value whereas open innovation is fully considered as a profit

oriented concept. Contemporary approach to crowdsourcing as a concept sometimes overlaps with open innovation because it remains under the broad umbrella of open innovation concept [32, p. 15-17]. It is a relatively new concept that refers to creativity and innovations within cooperation with stakeholders, including active prosumers. Following this approach, crowdsourcing is defined as [33, p. 189-196; 34, p. 76-87; 35, p. 210]:

- concept, which name is formed from two words: crowd, making reference to the people who participate in the initiatives, and sourcing, which refers to a number of procurement practices aimed at finding, evaluating, and engaging suppliers of goods and services;
- a type of participative online activity in which an individual, an institution, a non-profit organisation, or company proposes to a group of individuals of varying knowledge, heterogeneity, and number, via a flexible open call, the voluntary undertaking of a task;
- new web-based business model that harnesses the creative solutions of a distributed network of individuals through what amounts to an open call for proposals;
- a powerful approach for tapping into the collective intelligence of the broad-based community of Internet users;
- a model capable of aggregating talent, leveraging ingenuity while reducing the costs and time formerly needed to solve problems;
- knowledge platform which is enabled only through the technology of the web, which is a creative mode of user interactivity, not merely a medium between messages and people.

According to S. Marjanovic, C. Fry and J. Chataway, a key difference between crowdsourcing and open source innovation is that open source production is a cooperative activity generally enabled by a web-based innovation platform, frequently initiated and voluntarily undertaken by members of the public, and generally without attribution of traditional ownership and IP to a specific body. Moreover, the key difference between crowdsourcing and open source in comparison to traditional outsourcing is that in both crowdsourcing and open-source production, a task or problem is outsourced to a much wider pool of organisational and/or individual innovators [36, p. 325].

The essential idea of crowdsourcing is that a crowdsourcer (which could be a company, an institution or a non-profit organisation) proposes by online platform to an undefined group of contributors (individuals, formal or informal teams, other companies) the voluntary undertaking of a task presented in an open call by online platform [35, p. 200]. A lot of online crowdsourcing platforms are open to everybody who has access to the Internet and no specific training or expertise is needed to become creative partner and suggest on his own an idea or solution [37, p. 1146]. In turn, R.M. Bauer and Th. Gegenhuber [38, p. 664] argue that crowdsourcing does not necessarily rely on the Internet because sourcing actors can broadcast calls to the general public via mass media or public spaces, or disseminate calls to expert audiences (e.g. professional communities) through specialised media channels and professionals' formal and informal networks.

Crowdsourcing can be also partly included in the growing trend of marketing experience, where consumer wants to buy experience in the process of exploring, creating and modifying a product or service [39, p. 102]. Moreover, as a complex and flexible process, it may include sub-processes such as:

- crowdfunding – collecting different resources (funds, money, tangible goods, time) from the population at large through an Internet platform. In return for their contributions, the crowd can receive several tangibles or intangibles, which depend on the type of crowdfunding [40, p. 9];
- co-creation – joint creation of value by the company and the customer or other partners within innovation process; joint problem definition and problem solving [41, p. 8];
- micro-tasking – small tasks of a larger project (such as text recognition) executed by external partners [42, p. 146];
- art-sourcing – advanced form of crowdsourcing where the target community consists of various representants of art and design, including graphic designers, filmmakers, sound engineers, architects [42, p. 147];
- usage of crowd creativity – rational use of creative talent pools to design and develop original art, media or content [43, p. 203];
- usage of cloud labour – leveraging of a distributed virtual labor pool available on-demand to fulfill a range of tasks from simple to complex [43, p. 203; 44, p. 12].

Crowdsourcing within creative clusters can be the flexible process of obtaining feedback from end-users in at least three distinct ways [45, p. 20]:

- firstly, the absolute number of consumers/end-users consulted can be vastly increased, suggestions or developments can come not only from existing customers but from potential customers that previously the firm had no way of contacting;
- secondly, crowdsourcing allows firms to interact with consumers and cluster partners instantly and directly, there is no need for information to filter through (or not) from salespeople or other members of the distribution channels;
- thirdly, instead of consumers providing generalised ad-hoc suggestions on new products, firms can specifically tailor the areas of product development that they ask crowdsourcers to focus upon.

For example, crowdsourcing platforms such as Innocentive, 99designs, DesignCrowd, Sribu, CrowdSpring and many others offer the possibility of co-creation of creative products within creative industry development [46]. Innocentive is an open innovation and crowdsourcing platform that support organisations from all over the world in seeking solutions for different problems, where more than 375 000 registered solvers (with diverse and creative minds) from more than 200 countries work on solutions concepts. The company boasts a high, almost 50%, effectiveness in solving problems reported by customers. This platform offers ample opportunities for creative people, because for creative work they may receive financial awards. For example, by 2012, more than 1,140 ideas were awarded with the amount from 500 to 1 million dollars [47, p. 77]. Main motto of Innocentive as a global leader in crowdsourced innovation and software platforms is „Our Challenge Driven Innovation methodology and purpose-built technology result in fresh thinking and cost-effective problem solving, whether you want to crowdsource solutions from external Solvers or better harness the intelligence of your internal team. We offer a comprehensive suite of externally and internally-focused programs, providing the methodology, technology, expert support and problem-solving network for you to crowdsource solutions to important problems" [48]. In turn, crowdsourcing in cultural heritage area involves public participation in collecting, describing, categorising or curating photographs or manuscripts, as an expression of democratic participation and engagement in heritage, or an attempt to complete professional expertise with the knowledge of the public at large. It takes the form of working on a project for free or performing micro-tasks for a small amount of money [49].

International project of the Creative Commons can also serve as an inspiration for the development of crowdsourcing platforms and open innovation in creative clusters. This project supports free culture, creation and exchange of works treated as a common good and offers free legal solutions and other management tools that help creators to manage copyright of their works. The initiator of this initiative is an American non-governmental organisation founded in 2001 by scientists (mostly lawyers) and intellectuals engaged in the protection and promotion of common cultural property. The main tool offered by the project are the licenses allowing the replacement of the traditional model of "all rights reserved" for the principle of "some rights reserved" while respecting the principles of copyright. Through this solution, author of creative product can define rules on how he wants to share his work with others, having a choice of four different conditions for access to his work, which combine in six different licenses [50, p. 78].

The crowdsourcing concept in creative cluster can be implemented both at the macro and micro level. For instance, at macro level it is related to cluster and cluster organisation (cluster coordinator) and could be linked to the creation of organisational innovations (that improve cluster management) or marketing innovations (joint cluster offer). At micro level it is referred to cluster members and their autonomous organisations. Generally, the final aspect of the decision on implementing crowdsourcing within cluster at micro level or macro level is looking at the field from the perspective of tangible outcomes, i.e. how can different crowdsourcing model contribute to the working practices and what can different initiatives offer as real outcomes [43, p. 206]. The potential benefits of using crowdsourcing within creative cluster can include e.g. [34, p. 84; 37, p. 1145; 38, p. 668; 51, p. 9; 52, p. 10]:

- creative collaboration beyond the boundaries of organisations;
- faster design and prototyping, higher quality, greater elasticity;
- reduced lead time to market for new products and services by transforming the fuzzy frontend of new product development;
- access to new sources of external talents;
- flexible virtual network model for innovation;
- better engagement and retention of internal talents;

- lower costs R&D, including experimentations while simultaneously improving the quality of output;
- blending the best aspects of open source philosophy and the benefits of global business (including its outsourcing component);
- offering individuals in the crowd a chance at entrepreneurship, or at the very least an outlet for creative energy and creativity training;
- generating value from otherwise inaccessible creative expertise and critical items, as well as from increased execution capacity and bargaining power, non-mutually exclusive types of value;
- can be used not only for idea generation but for a whole range of tasks;
- helping to resolve challenges across products and processes, markets and business models;
- unrefined ideas can be converted faster into crystallised ideas that are aligned to product strategy by making them transparent across the enterprise, assisted by automation;
- helping to track ideas and make them visible to the right stakeholders early in the product development cycle for efficient collaboration;
- improving the success rate for new products and services by aligning innovation with customer expectations and strategic business priorities;
- encouraging to generate and develop ideas in order to create a culture of innovation – across the extended community of cluster including employees, partners, suppliers, and members through a system of incentives, collaboration and gamification;
- potential for grave economic and social impact.

Crowdsourcing can generate many valuable benefits. However, the idea of using the wisdom of the crowd cannot be taken indiscriminately. The main issue is the appropriate management of communities created for this purpose and optimal use of their collective intelligence [53, p. 184]. The correct implementation process of crowdsourcing at macro and/or micro cluster level can promote more efficient use of internal resources and acquire the necessary knowledge resources from the proximal and distal environment. The key advantages of crowdsourcing within cluster are related to the access to potentially huge amount of external creative labor that cluster members can have to execute their tasks, saving time and costs at the same time [45, p. 25]. Additionally, crowdsourcing can help to create, maintain and strengthen the creative community around the cluster brand and create a network of involved, committed people who will be the ambassadors of the brand or solution in the future [54, p. 28]. Based on crowdsourcing platforms, commitment in cluster development through knowledge transfer, is a way of achieving personal ambitions in cluster members, their need for self-realisation, building self-esteem, prestige and position in the cluster. Often, these factors are as important as the financial benefits resulting from the cooperation in the cluster environment.

Conclusion

Today, functioning clusters (including creative clusters) need effective solutions for a better coordination of knowledge management and innovation in internal environment. Many of the public institutions, interacting directly and indirectly through the cluster policies, highlight the need for continuous improvement in the cluster management. For cluster managers and cluster organisations (institutional cluster coordinators) this creates several new challenges, including those of strategic importance. An example of such a challenge, is to stimulate the involvement of cluster members in the design of open innovation using crowdsourcing.

Literature review indicates that implementation of crowdsourcing, can provide numerous benefits for cluster members, such as fast-gaining information of strategic importance for development (for instance, consumer and stakeholders preferences and needs, solutions for specific problems, ideas for creative products) or its use in designing appropriate changes. Thus, in order to ensure that the cluster has relatively stable conditions for development, it is necessary to exploit the potential that lies in the cluster collective intelligence and its external stakeholders.

Often, the advantage of creative clusters, essential for efficient implementation of crowdsourcing platforms at micro level (in specific cluster members' organisations) and macro level (in the cluster organisations responsible for the cluster development) is the presence of ICT companies that can design appropriate crowdsourcing platforms for clusters and its members. Moreover, they themselves and/or in cooperation with external companies, can provide full support in the implementation, information management, development and use of content. It is important to have ICT solutions that can be aligned to the specific needs of the cluster. The role of the cluster manager in this situation is to raise funds for this project and then, choose the best

offer. ICT companies - as cluster members and platform creators - know cluster organisation, key stakeholders and its value chain so that they are able to develop crowdsourcing platform considering not only technological parameters, but also cluster needs and expectations. It is important to highlight that this process requires close cooperation between the cluster manager and cluster members, integration of operations and setting mission and purpose of the project, so they feel part of the process. This kind of approach will increase their commitment and eliminate potential imperfections of this kind of platform, for knowledge transfer. Furthermore, the common experience in designing and implementing crowdsourcing at the macro level (cluster coordinator) can be transferred to micro level (autonomous organisation of the members of the cluster). Running this type of platform may be a strategic factor, both at macro and micro level, for enhancing level of competitiveness, enabling better communication in real-time and better understanding of their business challenges. Cluster members will have a real opportunity to co-create valuable solutions for cluster development through mutual knowledge sharing, experience and creativity in the virtual platform of knowledge.

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DETERMINANTS FOR DEVELOPMENT OF CLUSTER INITIATIVES IN POLAND AND UKRAINE

Abstract
The article analyses the problems of cluster development in Poland and Ukraine in order to identify directions for possible cooperation between the countries. Specificity and priorities of the national policies of clusters development, regional systems of support and examples of good practices of clustering in the both countries were considered. The comparative analyses of prospects for clusters development in Poland and Ukraine were conducted, the basic determinants influencing the cluster development were identified and evaluated. There were recognized the areas and direction of Polish-Ukrainian clusters cooperation including: the opportunities to projects conducting within the European Funds, the possibilities of bilateral cooperation of cluster members with the support of cluster coordinators, the feasibility of joint Polish-Ukrainian projects run in third countries markets.

Key words
Cluster, cluster initiative, national policy of cluster development, regional development, Polish-Ukrainian cooperation of clusters

Introduction

At present time the use of the cluster approach is regarded as one of the most effective mechanisms for the development of both economies of countries as a whole and their regions, as well as of individual companies. Cluster structures provide a significant impetus to the development of countries, allowing them to mobilise network resources of the territory organisation, and present one of the tools to ensure the competitiveness of countries in the world economy. Thus, according to the European Commission, 24% of the existing clusters are the world leaders, 37% — national leaders and another 24% — economic entities with strong competitiveness.

European clusters that are compatible with the most important EU documents play the role of organisations supporting regional development and ensuring the growth of innovation of the European Union. The same approach can be observed in Ukraine, where clusters play important role in developing scientific and technical potential of industry.

The precondition to achieve the economic growth both in Poland and Ukraine is an increase of the innovativeness of enterprises. Networking, sharing experience, cooperation, and collaboration support the process of innovations. Cluster is one of the most effectives platform to run those processes.

The advantages of the processes of clustering for participating countries are also as follows: a more efficient use of the potential of individual regions, diversification of the regional economy, growth in the number of taxpayers and expansion of the tax base, activation of the partnership dialogue "business — authorities", reduction of the budget dependency on some monopolistic business units.

The basis for effective cooperation in the implementation of initiatives on cluster creation is analysis of conditions, assumptions and perspective directions of cooperation in participating countries.

The aim of this article is to analyse the main determinants of the cluster initiatives development in Poland and Ukraine. The result of the analysis is to identify the factors that allow for the effective cooperation between clusters from Poland and Ukraine. Two research hypotheses are stated:

- Regarding the current level of development of cluster initiatives in Poland and Ukraine, there are moderate chances for the expanding the Polish-Ukrainian cluster cooperation.
- The European Union support programs are the basis for initiating cooperation between Polish and Ukrainian Clusters.

Using the secondary research methods such as analysis of existing (data desk research) and comparative analysis the hypotheses above have been proven.

The main purpose of the analysis of existing data was to outline the background for the formulation of the main determinants of clusters development in Poland and Ukraine. Particular attention was paid to national and regional policies of cluster development in both countries. The important element of desk research was also screening of financial support schemes occurring or being formed in Poland and Ukraine. Presentation of good practices helped to illustrate the current stage of clusters development.

On the basis of information collected at the stage of analysis of existing data, the comparative analysis was carried out. The following determinants – comparative criteria – for cluster development were formulated:

- Political situation
- Economic conditions
- Financial policy of supported clusters
- Availability of technical facilities
- Social capital
- International cooperation
- Readiness of entrepreneurs to cooperate in clusters
- Readiness of R&D institutions to cooperate in clusters.

For the purpose of the analysis "the scale of the positive impact of the determinant" was adopted with the scale of points from 0 to 5, where 0 - mean no impact and 5 - an excellent positive impact.

As a result of studies we proposed areas and directions of Polish-Ukraine cluster cooperation in the following scope:

- Possibilities of cooperation within the European projects
- Possibilities of bilateral cooperation of clusters' members with the support of cluster coordinator
- Possibilities of creating joint projects of Polish and Ukrainian clusters in third countries markets.

Analytics framework

Taking into account the urgency of the problem of cluster structures in economy, currently there also increases the amount of research concerning its various aspects: from the peculiarities of interpretation of the concept of "cluster" to choosing approaches to their identification and building, determination of directions and conditions of their effective functioning.

At present time in theory and practice there distinguished three main directions of defining the cluster, each of them highlights the main feature of their operation:

- regionally limited forms of economic activity within the related sectors usually attached to particular scientific institutions;

- vertical production chains, narrowly defined sectors, in which adjacent stages of the production process form the core of the cluster (the chain: supplier-producer-distributor-client), this category also includes the network formed around the major companies;
- industries identified at a high level of clustering (e.g. chemical cluster) or the aggregate of sectors at a higher level of clustering (e.g. agricultural cluster).

Therefore, it should be noted that the term "cluster" has different interpretations of scientists and practitioners and different meaning. One of the most common interpretations of the concept of "cluster" is offered by M. Porter. According to him, the cluster is a geographic concentration of interrelated companies, specialised suppliers, service providers, companies which operate in the same field and associated institutions (for example universities, supervisory units, trade associations and financial institutions) in their respective fields, competing but also cooperating. Clusters reaching critical mass (the necessary number of companies and other institutions making up the agglomeration effect) and achieving competitive success in the fields of their interest, are a remarkable feature of almost every national economy, regional, state, even the metropolitan, mostly in economically developed countries [1].

Scientists and practitioners distinguish various types of cluster structures in the economy. These cluster structures differ in the dimension of the following classification criteria: structure model, geographical location, organisational excellence, cluster structure, type of integration, model and stage of development, industry dependence, characteristic of relationships, orientation [2].

Recently so-called innovation clusters have gained a particular importance as drivers of the modern economic development. The innovation cluster, as the most effective form of achieving a high level of competitiveness, is an association of different organisations (research centres, industrial enterprises, individual entrepreneurs, bodies of state administration, public organisations, universities, etc.), which forms a system of dissemination of new knowledge, technologies, and innovations through networks of stable relations between all members of the cluster.

The aim of its operation is efficient transformation of inventions into innovations and innovations - in specific products and competitive advantages.

There is also a need to define cluster initiatives. In the literature there is a significant difference between clusters as the processes taking place in the economy and cluster initiatives. In practice, both in Poland and Ukraine, the terms cluster and cluster initiative are often used interchangeably to mean the actual initiative or even cluster organisations. O. Sölvell defines cluster initiatives as – "an organised effort aiming at intensifying growth and competitiveness of clusters in the region, which involves cluster companies, the government and/or research circles" [3].

European Commission defines the innovative clusters as a concentration of independent businesses – newly founded innovative companies, small, medium and large enterprises, and research organizations – operating in a particular sector, region, and founded to stimulate innovative activity by promoting intensive connections, sharing background facilities and exchange of knowledge, and expertise, and by contributing effectively to technology transfer, networking and sharing of information among companies within the cluster. Member countries should aim to achieve a proper balance between SMEs and large companies in the cluster to achieve certain critical mass, especially by specialisation in a certain area of research and development and innovation (R&D&I) and taking into account the existing clusters in the Member States and at Community level [4].

Currently, the EU policy and Europe 2020 Strategy are aimed at development of enterprises operating in networks or clusters, in which the R&D institutions are the important participant [5].

We can distinguish different types of clusters, but for accelerating the economic development the most desirable ones are clusters based on knowledge. The main added value of these clusters is to support innovative companies, using and implementing achievements of R&D institutions and benefits of networking.

The most effective and expansive regional innovation systems are not limited to sector or territory. On the contrary, the effective eco-innovation systems acting in line with the paradigm of Open Innovation, integrate different economical branches, interdisciplinary knowledge and various stakeholders. H. Chesbrough indicates

that the process of innovation is constantly increasing the role of the external partners of the company. Nowadays the company cannot conduct all research and development independently. It must be open to knowledge from outside, undertaking the cooperation with partner institutions, distributors, consumers (in the framework of market research) and other companies offering licenses and patents. The Open Innovation model assumes that the process of developing innovation by companies is based on both the external and the internal ideas. Due to it, companies share their knowledge in the form of licenses or patents, widen access to knowledge and reduce the cost of new technology and solutions [6].

The best form for the cooperation in scope of open innovation system is clustering. Companies operating in the cluster are independent – they compete with each other but at the same time in certain areas they cooperate or collaborate. The platform of cluster is also an important place for establishing links between companies and R&D institutions like universities, research institutes, educational institutions, science and technology parks, and certifying authorities or public administration as well.

Clusters, being at the same time specialised and interdisciplinary, with the network of functional and logistics interactions can create so-called “agglomeration effects”. They are able to play a key role in building regional specialisations and raising innovation and competitiveness of the region.

Clusters grow thanks to sharing knowledge between their members, the best adjustment to local potential and use of the all types of resources available in a given region. This is due to the intense interaction and cooperation, dialogue and coordination that take place parallel with the natural economic competition between members. Competition contributes and optimises the use of internal strengths and resources of companies and other members of the clusters in order to stimulate innovations. Cooperation within the cluster enables the effective usage of complementary internal resources and accelerates the development of innovation, thanks to a new combination of different resources.

The importance of clusters initiatives for regional development in Poland and Ukraine: National policy of clusters development in Poland

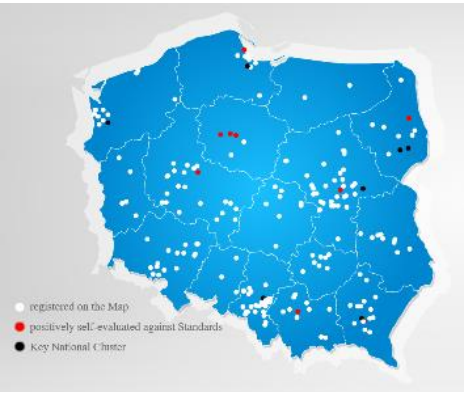

Fig. 1. Map of clusters in Poland, Source: [8]

The shape of the cluster system in Poland stems from the Mid-term National Development Strategy 2020, which implies an increase in the use of innovative solutions through clusters. According to the Strategy, the role of clusters on the macroeconomic level is to increase the competitiveness of Polish enterprises and lead to: combining companies, academic institutions and their resources, in order to bring knowledge faster to the market and on the microeconomic level they are: “modern instrument strengthening regional or local specialisations” [7].

The document "Strategy for Innovation and Economic Efficiency «Dynamic Poland 2020»" refers to clusters as an instrument of implementation smart specialisation in Poland. According to this document, clusters constitute an effective mechanism to concentrate resources and means and are one of the most diagnosed ways of stimulating innovation and horizontal cooperation in the economy.

The reference to the cluster is also found in the Programme for the Development of Enterprise 2020 in the context of cooperation between enterprises of the sector of scientific research and development of new products and services better tailored to the needs of consumers. According to the document, an important factor in making research and innovation by enterprises can be of service offered by professional organizations acting managing clusters.

A similar approach to the importance of clusters presented the Polish Cluster Policy Group, which has produced a document entitled “Directions and policy guidelines cluster 2020”. The Group presented recommendations

on cluster policy measures and instruments for the period 2014-2020. These recommendations can be summarised as follows:

- Development of existing clusters and founding new ones should be implemented by supporting cluster initiatives and cluster coordinators;
- Clusters that are the most important for Polish economy and competitive on international scale (world-class clusters) should be nominated and named as Key National Clusters;
- Development of key national and regional clusters should be stimulated by support granted not only to cluster coordinators but also directly to cluster actors, i.e. enterprises, research organisations and business support institutions;
- Support for basic coordination functions should be available on regional level;
- Dedicated support for internationalisation should be available for coordinators of Key National Clusters;
- Key National Clusters would be appointed throughout the entire financial perspective on a competitive call basis after validation against precisely defined criteria and requirements;
- In order to ensure credibility and transparency, it is necessary to establish an Evaluation Committee composed of representatives of ministries and government agencies and complemented by independent experts with different backgrounds;
- Key National Clusters would receive wide public support for R&D, production infrastructures, development of human capital, promotion and internationalisation;
- Regions should also establish priorities of their own development policies by pointing to key regional clusters that would define their smart specialisations;
- Public support should be offered for collaborative projects undertaken by entities operating in key clusters [9].

According to the goals of cluster policy outlined by the Polish Cluster Policy Group, the profile of a National Key Cluster (NKC) was created. It resulted from combination of expectations towards the best clusters in different states, especially European, and the actual performance of Polish clusters. However, after the first round of selection of NKCs, which was conducted in mid-2015, aroused a huge debate over the selection criteria and the result of the choice of the 7 National Key Clusters:

- Association West Pomeranian Chemistry Cluster “Green Chemistry”,
- INTERIZON - Polish ICT Cluster,
- Metal Cluster,
- Eastern Construction Cluster,
- Mazovia Cluster ICT,
- Polish Aluminium Cluster,
- Aviation Valley.

The above presented selection of National Key Clusters indicates a kind of decisive chaos in the Polish authorities in terms of defining the national specialisation which should be developed in clusters and which is worthy to be supported with public funds. There is the weak association of the NKC specialisation and regional specializations.

It is not clear up today what kind of support for NKCs and other clusters the Polish government presumes.

In 2015, Polish Agency for Enterprise Development (PARP) has conducted an inventory of clusters in Poland, as a result 134 clusters were identified, which were created between 2003 and 2015, with the majority (over 60%) are young clusters, i.e. those which arose between 2011 and 2015. The oldest clusters are 12 years old and the average age is over 4 years.

The importance of clusters initiatives for regional development in Poland and Ukraine: National policy of cluster development in Ukraine

For modern Ukraine the formation of innovative clusters is an opportunity for effective restructuring of the economy for reaching a new level of international relations in the economic sphere. The need for the clustering of Ukraine’s economy is considered periodically in the Cabinet of Ministers of Ukraine since 2003. However, presently the legal basis of their formation practically is not defined in the country. The official interpretation of the term “cluster” is missing in the basic legal acts adopted in Ukraine, but there can be found quite various

word-combinations concerning the concept: “innovative structures”, “innovation cluster”, “cluster model of development”, “territorial scientific and industrial clusters”, etc.

Since the legal status of clusters is undefined at the official level in Ukraine, their state registration and accounting is not carried out, and in this respect it is quite difficult to determine their actual number in Ukraine. According to various sources, about 35 clusters have been created and up to 100 of cluster initiatives, including transborder ones, have been found in Ukraine [10]. At the same time it can be argued that a large number of enterprises in the country operate according to the cluster approach. Table 1 presents some of the cluster formations operating in economic regions of Ukraine.

Table 1. Cluster formations operating in economic regions of Ukraine

Economic region	Priority directions of cluster development	Currently operating cluster structures
Podilskyi: - Vinnytsia region - Ternopil region - Khmelnytsky region	Mechanical engineering, support of the existing clusters (garment, construction, food, tourism)	- the Khmelnytsky construction cluster, the Khmelnytsky garment cluster - the Kamianets-Podilskyi tourism cluster - the agri-tourism cluster “Oberigh” (“Amulet”) (Grytsiv village, Khmelnytsky region) - the innovation-investment cluster (Ternopil) - the Vinnytsia food processing cluster
Karpatsky: - Zakarpattya region - Lviv region - Ivano-Frankivsk region - Chernivtsi region	Chemical, food, recreation and tourism, wood processing, crafts, garment, construction, automobile industry	- the souvenir production cluster “Suziria” (“Constellation”) - the transport and logistics cluster of Zakarpattya region - the tourism cluster (“Seven Wonders of Ukraine”) - the Lviv cluster of IT and business services - the biotechnology cluster
Prychornomorsky (Black Sea region): - Mykolayiv region - Odessa region - Kherson region	High technologies, shipbuilding, microelectronics, agriculture, fishing, logistics, recreation and tourism	- the transport and logistics cluster “Southern Gates of Ukraine” (Kherson) - the cluster “Transit Potential of Ukraine” (Odessa) - 3 clusters in Prydunavie (Danube region), - 5 clusters in Mykolaiv region
Polisky: - Volyn region - Zhytomyr region - Rivne Region - Chernihiv region	Agriculture, food, eco-tourism, wood and granite processing	- the wood processing cluster (Rokytne district, Rivne region) - forest clusters - tourism and recreation clusters
Donetsky: - Donetsk region - Luhansk region	Mechanical engineering, chemical, mining, metallurgy, food, processing industry	- the national innovation cluster "New Technologies for Management of Natural Resources" - transborder nanoclusters
Prydniprovsky (Dnieper region): - Dnipropetrovsk region - Zaporizhzhya region - Kirovograd region	High-tech (aero, electronics, biotechnology), mechanical engineering, metallurgical, chemical, food and processing industry	- the national innovation cluster "New Machines" and construction cluster (Dnipropetrovsk) - the innovative technology cluster "AhroBUM" and the honey cluster "Bees Know No Borders" (Melitopol) - the food cluster "Buy Zaporizhzhya Products, Choose yours" (Zaporizhzhya)
Eastern: - Poltava region - Sumy region - Kharkiv region	High technologies, chemical, mechanical engineering, metallurgy, metalworking, electricity, food, fuel industry, agriculture, tourism	- the regional cluster of ecologically clean agricultural production (Poltava region) - the Sumy cluster of ecologically clean agricultural products - the Sumy construction cluster

Economic region	Priority directions of cluster development	Currently operating cluster structures
		- the Kharkiv technology park "Technopolis" - a cluster of alternative energy and scientific and educational cluster Also - aviation, space sphere, power engineering, pharmaceutical, nanobiotechnologies, health care, armored vehicles, agriculture and mechanical engineering
Central: - Kiev region - Cherkasy region	High-tech (new material), construction, mechanical engineering, food, agriculture, tourism	- the national innovation cluster "Energy for Sustainable Development" (Kiev, Polytechnic Institute) - the national Innovation cluster "Technologies of Innovative Society" (Kiev, Polytechnic Institute) - the national innovation cluster "Innovation Culture of Society" (Kiev, T. Shevchenko KNU) - the national innovation cluster "New Food Products" (Kiev region)

Source: [11]

In order to implement the legislatively defined priorities of innovation activity, and taking into consideration the existing potential and regional initiatives, the State Agency of Ukraine for Investments and Innovations is working on the creation of 10 national innovation clusters, namely: “New Machines” (Zaporizhzhya), “New Materials” (Kharkiv), “Biotechnologies” (Lviv), “New Food Products” (Kiev and Kiev region), “New Technologies for Management of Natural Resources” (Donetsk), “Innovation Culture of Society” (Kiev), “New Power Plants and Movers” (Zaporizhzhya), “Energy for Sustainable Development” (Kiev), “Transit Potential of Ukraine” (Odessa), “Information Society Technologies” (Kiev), “Agricultural Engineering” (Melitopol), “Rocket Engineering” (Dnipropetrovsk), “Mining Engineering” (Kryvyi Rih), “Instrument Engineering” (Zhovti Vody, Dnipropetrovsk region), “Metallurgical Engineering” (Dnipropetrovsk) (The State Agency of Ukraine for Investment and Development) [12, 13].

Innovative clusters of power engineering (the core of the cluster is JSC “Turboatom”), pharmaceutical production, nano- and biotechnologies in Kharkiv region can become promising national clusters in Ukraine. Thus, the role of a high-tech knowledge-intensive cluster of power engineering for Ukraine can be estimated by the number of Kharkiv enterprises cooperating with 40 world countries.

The first six clusters in Ukraine were formed in Khmelnytsky region in 1998-2000 with the assistance of the Association “Podillia Pershy” and international programs of economic recovery of Podilsky region with appropriate financial assistance of the United States Agency for International Development. In this period the garment, construction, food, tourism clusters and cluster of agri-tourism were created [14].

Three different by size and geographic location territorial units — the city of Khmelnytsky (regional centre), the city of Kamenets (district centre), Grytsiv village of Shepetivka district (rural centre) became the centres of joining business structures into clusters. In order to disseminate the cluster experience to other regions of Ukraine, Association “Podillia Pershy”, along with the Institute for Competitiveness (Kiev) have developed a project of creating in Ukraine training centers, which could spread the experience of clustering in their regions and introduce it into practice by establishing cluster associations in priority for each region areas.

The first centre was established in the city of Khmelnytsky with the support of the Khmelnytsky Regional State Administration, Khmelnytsky National University and the Association “Podillia Pershy”. The Association Executive Board, together with the Institute for Competitiveness, have started realising a new project “Clustering of the Industrial Sector as an Effective Way of Regional Development”, which implementation actively began in late September 2003. The project aim is to help local governments and public organizations to implement the programs of joining enterprises into clusters in other regions of Ukraine.

However, not all of the formed clusters developed successfully. Some clusters in Khmelnytsky region showed a relatively high viability (construction and garment clusters, the cluster of agri-tourism), but vital activity of the others proved to be impossible.

The reasons why the clusters are successful whether not are analyzed in [14]. The construction cluster in the city of Khmelnytsky succeeded indeed. In 1998 it gathered about 30 enterprises of the construction industry in the region. For the period of its operation thousands of new jobs have been created, the cluster has occupied leading positions in a difficult and competitive housing market, providing mobility, flexibility, innovation and high quality of work at making commissions from the population.

The Khmelnytsky garment cluster was the first association of business structures of this type in Ukraine. It began developing in 1997 with the participation of Technological University of Podillia (now Khmelnytsky National University), Chamber of Commerce, Main Department of Economy of Regional State Administration, a number of banks and enterprises of the garment industry. The students' Fashion House became the cluster innovation center. Due to the design developments, modeling and creation of new products, teaching and training of students and entrepreneurs in the cluster structures in Poland and Italy, the cluster participants managed to reach the production and commercial success [15].

Potential possibilities of Podilskyi region of Ukraine, which has enormous cultural and historical traditions, unique natural resources and favourable geographic location, contributed to the efficient functioning of the tourism cluster in the city of Kamianets-Podilskyi and successful development of the agri-tourism cluster in Grytsiv village of Shepetivka region, which became well-known not only in Ukraine but also abroad.

However, despite considerable efforts, the dairy cluster in Khmelnitsky was not created. The food clusters in Kamianets-Podilskyi and Khmelnytsky, which successfully started their activities in 1999-2000, could not withstand competition in the food products market and at losing some of their participants (due to bankruptcy of some enterprises) faced serious problems in their operation.

However, in 2005 in Khmelnytsky region there began a new phase of clustering in economic sectors attractive in terms of innovation and investment, namely: in the manufacturing of construction materials, organic farming, horticultural farming, information and education sector, in the field of commercial use of historical and cultural heritage, and others [15].

In Ivano-Frankivsk region there were created crafts clusters, which began functioning in 2000 [16]. The initiative of their formation came from scientists of Carpathian National University, who brought together dozens of craftsmen, individual manufacturers, entrepreneurs, intermediaries, representatives of science and public institutions on a voluntary basis. The purpose of the association is to support the development and protection from competitors of a typical for the area industrial activity, in particular, manufacturing of various products from sheep wool.

A wood processing cluster was created in Rivne region on the initiative of Chamber of Commerce with an active support of the region's business circles and financial assistance of the "Eurasia" fund. The clustering of over 30 private sawmills and wood processing enterprises, design and research institutions, design centers allows to achieve more efficient use of local forest resources, to move from making simple and primitive products (sawn timber, pallets) to producing more complex ones with a larger share of added value, such as furniture for homes and offices, souvenirs and other products [16]. Three clusters — in agricultural production, mechanical engineering and construction have been formed in Zhytomyr region [13].

Forming a cluster of green tourism has been stated and a project on creating a regional cluster of ecologically clean production manufacturers is being implemented in Poltava region. The regional organization of employers has developed a pilot project on forming the agricultural products cluster in Odessa region [15].

An innovative industrial cluster in agricultural engineering is being formed in Zaporizhzhya region as well. The founders of the industrial cluster is the Dnipro Regional Center of Innovation Development, the Pridniprovsky Scientific Center under NAS and MES of Ukraine, Taurian State Agrotechnical University, the public organisation "Technology Park «Mechanical Engineering Technology»", the public organisation "Innovation and Technology

Cluster «AhroBUM»" [15]. The creation of such a cluster is aimed to boost the manufacturing of competitive innovative products in the field of agricultural engineering which will be consumed not only in the country but beyond its borders as well.

National and regional support systems of **clusters in Poland**

Polish cluster policy is implemented in the following areas:

- research and development (R&D),
- support of the international expansion of companies operating in clusters,
- development of human capital in enterprises – members of the clusters,
- stimulation of the scientific-industrial collaboration within the clusters,
- creation of new enterprises.

So far, public support for cluster development in Poland was carried out indirectly through the financing of cluster coordinators and their services for the members of the cluster, but mainly financial support was dedicated to investment in common infrastructure.

New approach for supporting clusters through the National Key Clusters (NKCs) and the Regional Key Clusters (RKCs) was formulated in 2015. NKCs will be supported from the funds of the national level and RKCs will be financed from regional funds.

According to the present Polish cluster policy, the choice of NKC and RKC will result in a concentration of public national and regional funds, including funds from the European Union. NKC and RKC will be supported in a targeted manner with public funds available at national level, especially dedicated to the expenditure on R&D and establishment the cooperation of R&D and companies. Taking into account the independence of the regional decision-making processes, different methods of selecting Regional Key Clusters can be observed - accreditation, competition or processes of analysis, public consultancy, etc., related to the regional smart specialization strategies. It should be noted that regardless of the status of the cluster - National Key Cluster or Regional Key Cluster - clusters are usually regional in nature.

The new cluster policy maintains support for the cluster coordinators, but forms a more comprehensive model of cluster-based development policy. It assumes the coordination and concentration of various instruments of public policy for cluster development areas as arising innovation, science and technology progress, human resource development etc. In practice - the applications of NKCs will be awarded by additional, extra points in the system of evaluation of projects. In this way, a new cluster policy responds to the shortcomings of the coordination of the activities of government (government failure) and the complexity and disintegration of the support system (systemic failure).

Proposed trends and assumptions for the Polish cluster policy include mechanisms to support the development of cooperation and coordination, including incentives for stimulation of the new cluster initiatives in regions of a significant potential for economic, scientific and technological input. The special economic zones seem to be a promising area for establishing the new clusters. It is also prospective to stimulate the creation of new interdisciplinary clusters and cluster initiatives at the interface between different sectors and industries in order to solve major socio-economic problems. Clusters could be the answer to the problem of market imperfections (market failure), associated with the existing constraints in Poland in the establishment and development of cooperation between businesses, and between industry, R&D institutions and administration as well.

The cluster policy is also a response to the diagnosis of the current state of development of clusters and cluster initiatives in Poland. The reports and analyses show that cluster initiatives do not always arise there where statistical diagnoses indicate the existence of significant appropriate conditions for clusters development.

The cluster policy does not assume, however, creating a top-down cluster initiatives, but constructs a system of incentives, mobilising their grassroots with bottom-up relations of generation and, more importantly, engaging cluster's stakeholders in the processes, strategic development planning and defining common ventures. The main actors appealing in these processes will be companies and business environment institutions. It is also assumed that the main determinant of the development of clusters should be private investment carried out

by the cluster members. Public support for clusters should be regressive and limited in its duration. It should be gradually discontinued.

These assumptions for the Polish policy to support clusters are in line with the EU 2020 Strategy and the concept of smart specialization on the national and regional levels as well, postulated by the European Commission.

EC assumes that each European country and region should concentrate efforts and resources on specific, small number of priorities, or economic specialisation of significant innovative potential, which has a real expertise and resources and can achieve excellence and competitiveness on a global scale. Preparation of smart specialisation strategies at national and regional level is subject to the granting of EU funds for investments in research, development and innovation in 2014-2020.

National and regional support system of clusters in Ukraine

The policy of clusterisation of Ukrainian economy has been considered by the government of the country since 2003 [17]. Thus, the Resolution of the Cabinet of Ministers of Ukraine (CMU) of 28.07.2003 №1174 "On approval of the State program of industrial development for 2003-2011" provided for the formation of technological clusters primarily in the most knowledge-intensive and high-tech sectors and manufactures which can radically change the economic, as well as scientific and technical potential of the industry, ensure optimization of regional industrial complexes and production facilities. In 2008 the CMU Resolution of 14.05.2008 "On approval of the State Target Economic Program «Creation of innovation infrastructure in Ukraine for 2009-2013»" made provisions for creation with the assistance of local authorities of innovation and technology clusters in the structure of research organizations, small and medium enterprises, technology transfer centers, etc. At the same time, the CMU Resolution №389 of 02.02.2011 approved "The program of investment and innovation activity in Ukraine", which pointed out the innovation infrastructure underdevelopment, lack of innovative enterprises (innovation centres, technology parks, technopolises, innovative business incubators), science parks, technology transfer centres and industrial clusters. Finally, in 2011 there was adopted the Law of Ukraine "On priority directions of innovation activity in Ukraine" №3715-VI of 08.09.2011, which specifies that for the implementation of medium-term priority directions the state will introduce measures concerning the development of the innovative infrastructure (innovation centres, technological parks, scientific parks, technopolises, innovative business incubators, technology transfer centers, innovation clusters, venture capital funds).

Along with the general regulations on the creation of clusters, the practice of adopting special regulations is widely spread in recent years. Thus, by the Ordinance of the CMU №165-p of 27.01.2010 there was approved the "Action Plan for 2010-2011 on Creating innovation and technological cluster "Sorochyntsi Fair" and the Ordinance of the CMU №145-p of January 27, 2010 "On introduction of cluster model for development of folk artistic crafts" was adopted.

The need to promote cluster initiatives is mentioned in some elaborated by the regions and approved strategies of socio-economic development, but these projects did not receive efficient support.

A particular importance in recent years is attached by the Government of Ukraine to the creation of transborder clusters. This is justified by the Ordinance of the CMU of 10.09.2008 №1214 "On approval of the plan of measures on realization of National Security Strategy of Ukraine for 2008", which provides for development of the strategy for creation of regional transborder clusters.

The concept of the State Program of developing transborder cooperation for 2007-2010 considers transborder cooperation as "a complex of joint activities aimed at establishing and deepening economic, social, scientific, technical, environmental, cultural and other relations between territorial communities, their representative bodies, local executive authorities and territorial communities, corresponding authorities of other countries under agreements concluded between such entities of transborder cooperation.

Thus, the laws of the Verkhovna Rada of Ukraine, resolutions and ordinances of the Cabinet of Ministers provide for the establishment of territorial and sectoral clusters. However, it should be noted that besides the recognition of clusters as instruments for implementation of programs aimed at innovations in normative and

legal acts of Ukraine, real mechanisms to create the conditions for successful implementation of the policy of the economy clusterisation have not been suggested and these processes occur somewhat spontaneously, without proper organisation of the process by the state.

In general, it should be noted that there are conditions for cluster-based economic development in Ukraine. At the moment, individual strategies for development of clusters and cluster initiatives have been approved, but there are no corresponding recommendations on their formation and support.

Thus, the main problems of clustering in Ukraine are the following [11, 18-21]:

- The lack of an adopted at the state level concept of industrial policy, neither of cluster policy.
- The imperfect legal framework for the establishment and development of cluster formations in the country. None of the articles of the Commercial Code regulates such type of enterprise associations as clusters indicating the corresponding conditions for carrying out their economic activity.
- The inadequate programme-targeted framework for ensuring the implementation of cluster strategies. The existing programmes are mostly oriented to individual branches of the national economy instead of manufacturing the high-tech products.
- The lack of proper communication between science, business and authorities. This problem is caused by inefficient public-private partnership in the field of development, testing and implementation of innovative decisions in activities of economic entities, which complicates the possibility of adapting new technologies at domestic enterprises.
- However, today there is quite a wide range of existing institutions whose activity is aimed at facilitating the implementation of transfer exchange with innovations, namely: Ukrainian Center of Innovations and Patent Information Services, European Network of Innovation Relay Centres (IRC-network), National Information Centre for EU Cooperation in Science and Technology, Ukrainian Technology Transfer Network (UTTN), Public Network for the Transfer of Ideas in Technologies ("TIT network" or Web TIT), etc. [19], but these processes are hardly implemented.
- The low level of institutional environment for supporting implementation of innovations and business development caused by the lack of government incentives and funding of science and academic entrepreneurship (type of economic activity based on creation of new technologies and processes, the main purpose of implementation of which is to optimize production and management processes at enterprises).
- The unsatisfactory level of the infrastructure development (primarily technical) constraining the development of research activities and therefore innovations.
- The prevalence of corruption mechanisms in government warranties, special-purpose funding, public financing and tendering, which contributes to the development of money laundering schemes and does not ensure the implementation of national investment and innovation programmes.
- The insufficient interest of small and medium businesses in association into major production systems through the lack of preferences related to venture activities and technological upgrading of fixed assets.
- The non-availability of credit resources required to implement innovation projects for participants of cluster formations.
- The lack of skilled innovation managers, whose function is to monitor market innovations, substantiation of expediency and integration of innovative approaches in economic activity at all levels.
- The low level of transparency and trust among potential members of clusters, including extremely low confidence in the government.
- The lack of experience in public-private partnerships and legal problems with its implementation.
- The lack of experience of companies CEOs and R&D institutions in participating in international projects and programs as well as the appropriate consulting support of these processes by experts.
- The ineffective government policies on establishing and maintaining international cooperation of Ukrainian producers with foreign partners.

Thus, unfortunately, the formation and development of clusters in Ukraine is progressing slowly. A very small number of clusters created in different regions of Ukraine can be attributed to the export-oriented innovation cluster structures. With concern for the future of the country we can assume that Ukraine, being in permanent complex crisis, has not developed a clear program of the economic development and principles of building partnerships between business entities and for this reason is still far behind its European neighbours.

Under these conditions, the most important tasks include: carrying out administrative-territorial reforms, reducing bureaucracy of the state apparatus, combating corruption and lobbying by authorities the interests of oligarchs, as well as supporting business development, assisting the establishment of small and medium businesses, and every other support of cluster initiatives.

Examples of good practice of clustering in central Poland

Innovative clusters are not only high technology clusters, but also clusters of low- and medium-technology, such as cooperative network – Bioenergy for the Region Cluster (B4R). This cluster is a cooperation platform of companies, research institutions, local administration and business support institutions. The main aim of the B4R is sustainable energy development in Central Poland. In the context of climate change the cluster promotes innovative solutions in renewable power engineering in local and regional dimensions.

Cluster aims to achieve its purposes through:

- Complex solution of issues concerning the regulation of the biomass market in Central Poland, in particular the methods of collection, processing and use as a renewable energy source (RES);
- Integration of members of the Cluster - businesses, researchers and local authorities in order to increase the share of solar and wind energy in the energy balance of the region;
- Educational and information activities, promoting the use of renewable energy and energy efficiency.

Renewable energy sources industry is not only one of the most dynamically developing areas of business, but it may be regarded that is one of the most ground-breaking, positive and remarkable achievements of the global economy the last few years. The processes of transition to a low-carbon economy, free from fossil fuels, are partially the result of the obligation imposed on governments and national economies by international organizations, primarily the United Nations Framework Convention on Climate Change - UNFCCC or FCCC and the Kyoto Protocol, but, most of all, they are the result of environmental-friendly social trends all over the world.

Development of RES effects introducing to the market of new climate-friendly technologies and innovative energy production solutions [22].

Bioenergy for the Region Cluster came into being in April 2007 and is an open initiative of the cooperative network, which, at the end of 2015, consisted of 67 companies, 9 R&D institutions, 10 local administrations and 11 business environment institutions, plus regional TV and radio. In July 2014 the Renewable Energy Sources Technology Transfer Centre (RES TTC) was opened as the research facilities for companies and other stakeholders of the B4R cluster. In 2012, the cluster was recognized by the Polish Agency for Enterprise Development as a cluster of supra-regional importance for Polish economy. Cluster members are, for example, Veolia Lodz, Polish Energy Group, Technical University of Lodz, University of Lodz, Lodz Regional Science & Technology Park, and many other institutions working together for sustainable energy development in Central Poland.

The heart of the cluster beats in RES TTC, located in Konstantynów Łódzki, neighboring Lodz – the third largest city in Poland. RES TTC is an interdisciplinary research center equipped with state-of-the-art research and technical facilities, conducive to the transfer of knowledge and technology as well as increasing the innovation potential of enterprises participating in the „Bioenergy for the Region" Cluster. RES TTC supports the integration of the business and scientific community in the sector of sustainable energy in Central Poland, as well as tying bilateral and multilateral scientific and industrial consortia, particularly at international level. It consists of 8 interdependent laboratories:

- Biomass Lab
- BioProcess Lab
- Solar Lab
- Wind Energy Lab
- Energy Efficiency Lab
- E-Mobility Lab
- Textronics Lab
- Circular Economy Lab.

Bioenergy for the Region Cluster distinguishes among others mainly due to undertaking intensive international cooperation.

Another good practice of cluster initiative in Central Poland is Mazovian ICT Cluster, which was established by Market Consumption and Business Institute in 2007, currently it has more than 140 committed participants - 5 Research Institutions, 6 Universities and plenty of other entities including SMEs, NGOs, investment funds and large companies. The mission of the Mazovian ICT Cluster is to bridge the gap between the action and conditions for SME's development in the metropolitan area and the rest of the Voivodship. Cluster accomplishes this mission by establishing and developing cooperation between sector of computer science enterprises, telecommunication and electronic media R&D units, universities and business institutions and local authorities in the area of Warsaw and outside metropolitan areas.

The competence areas of the Mazovian ICT Cluster are: telecommunication, IT, industrial automatics, power engineering, GIS, Business System Solutions, Creative Industry, Smart City, Smart Grid, eHealth, Decision Support System. In each area has a front runner with the associated entrepreneurs, who cooperate closely in the new projects and the technological solutions. In 2015, Mazovian ICT Cluster obtained a status of National Key Cluster as one of seven entities in the country. Next year the cluster also received Silver Label of Cluster Excellence, certified by European Secretariat for Cluster Analysis (ESCA).

Similarly to B4R, Mazovian ICT Cluster implements international projects. One of them - Cluster Excellence for Creative Industries Leadership unites European clusters to drive cluster excellence and provide top professional support services in the digital cultural and creative industries. In its scope the first European Strategic Cluster Partnership (ESCP) on digital cultural and creative industries is being created [23]. The common feature linking clusters, which can be named as good practices, is conducting numerous projects, especially the ones in multinational partnership. This type of projects provides models, standards and examples of solutions, which are then implemented within a cluster.

Examples of good practice of clustering in Ukraine

Clusters and cluster initiatives in the transborder space are implemented most actively in Ukraine. Six Euroregions – "Bug", "Upper Prut", "Lower Danube", "Carpathia", "Dnieper" and "Slobozhanshchyna", in the operation of which such regions as Volyn, Zakarpattya, Ivano-Frankivsk, Lviv, Odessa, Chernivtsi, Chernihiv and Kharkiv are involved, were established at the state border of Ukraine.

On the basis of the provisions of "European Convention on Transfrontier Cooperation between Territorial Communities or Authorities" and "European Charter of Local Self-Government", Lutsk, Chernivtsi, Zakarpattya, Odessa, Ivano-Frankivsk and Lviv regions of Ukraine together with administrative and territorial communities of Poland, Belarus, Romania, Slovakia, Hungary, Moldova, Austria, Germany and France moved to the practical application of their transborder business opportunities. Namely, the neighbourhood programs "Poland – Belarus – Ukraine", "Hungary – Slovakia – Ukraine" and "Romania – Ukraine" aimed at improving the socio-economic situation in border regions has been launched. Table 2 shows the clusters and cluster initiatives currently operating in the transborder space of Ukraine.

Table 2. Clusters and cluster initiatives in the transborder space of Ukraine

Cluster / cluster initiative	Characteristics
Clusters	
Transborder logistics cluster (*Zakarpattya region)*	It was planned according to the Programme of creation of transborder transport and logistics centres as a structural unit of innovation clusters in Zakarpattya region for 2009-2011
Scientific information and statistical cluster "Infostat–Ukraine–Poland" (*Ukrainian–Polish transborder region, Lviv region*)	The cluster has been functioning since 2013. The participants of the cluster from Ukrainian side are: SI "M. I. Dolishny Institute of Regional Studies of NAS of Ukraine", Main Department of Statistics in Lviv region, Ivan Franko Lviv National University, Lviv Regional Association of Economists of Ukraine, from Polish side: Department of Statistics of

Cluster / cluster initiative	Characteristics
Clusters	
	Subcarpathian Voivodeship, Rzeszów University; Centre for Statistical Research and Education, Central Statistical Office of Poland
Transborder tourism and recreation cluster *(Ukrainian-Polish transborder region)*	It was created within framework of the Neighbourhood Programme "Poland-Belarus-Ukraine" for 2007-2013
Lublin Eco Energy Cluster	It began functioning as a transborder cluster by attracting participants from the Ukrainian side, namely, the "Centre for Introduction of Alternative and Renewable Energy Sources". The cluster also includes a holding structure, which has a unit in Ukraine - JV "LLC ComEcoLviv"
Polish-Belarusian-Ukrainian Transborder Tourism Cluster (*Volyn region)*	The agreement on the establishment of the cluster was signed on 31.10.2014. The parties to the Agreement are: Lublin Regional Tourism Organisation, Volyn tourism cluster and Brest tourism cluster. It was created within framework of the Neighbourhood Programme "Poland-Belarus-Ukraine" for 2007-2013
Cluster initiatives	
According to the project "National Strategies of Creation and Maintenance of Transborder Clusters" there were presented two transborder cluster initiatives: 1) the transborder forest cluster (as part of border Carpathian regions of Ukraine and neighbouring countries); 2) the transborder tourism and recreation cluster (also as part of Carpathian border part of Ukraine and neighbouring countries) *(Ivano-Frankivsk region)*	As in 2016, these cluster initiatives have not been implemented yet, but they have a considerable potential of functioning
The agreement on the establishment of "Transborder Innovation Cluster" between Chełm Chamber of Commerce, Ltd and East European Ukrainian University *(Ivano-Frankivsk region)*	The agreement was signed on 19.02.2015. The aim of the cluster is to organise professional practices in Poland for students of Eastern University in the scope provided by the university curricula
According to the Concept of the State program of transborder cooperation for 2011-2015, there considered a possibility of establishment of transborder tourism cluster based on the network of regions-winners of the all-Ukrainian contest "Seven Wonders of Ukraine" *(Chernivtsi region)*	The activity concerning the cluster development is expected to be performed using the potential of the Euroregion "Upper Prut" (Ukraine, Moldova, Romania)
A declared cluster initiative - Ukrainian-Romanian "First Agrarian Cluster", which was launched in 2009 in Chernivtsi region. The planned cluster area: Chernivtsi region, neighbouring areas of Khmelnytsky, Ternopil, Ivano-Frankivsk regions (Ukraine); Botosani and Suceava County (Romania); Moldova	The cluster activity is aimed at: increasing the innovation level of agricultural activities; improving the investment climate for the industries belonging to the cluster; developing the mechanism for supporting innovation activities of enterprises by regional authorities and local self-government bodies; creating the system of training specialized personnel for agribusiness of the region; providing Ukrainian fruit and vegetable market with organic products; selling berries and mushrooms to the countries of Western Europe. The objectives contribute to the development of interaction between enterprises, producers, certification inspectors, transporters and consumers of the products. All the entities included in the cluster interact on the basis of the conducted agreements.

Source: [24]

Moreover, at the border with Belarus there was established transborder agri-tourism cluster "Dnipro" (2010), which combines six neighbouring border areas of Gomel and Chernihiv regions, namely Dobrush, Gomel, Loyev,

Gorodnya, Chernihiv, and Ripky districts. The main objective of functioning of this transborder cluster is promoting ideas and principles of sustainable development of agri-tourism as a direction of sustainable socio-economic development of rural areas of Gomel and Chernihiv regions, and, in the future, of Bryansk region. This, in turn, will allow to implement this tourism project in the foreign market for tourism services with a joint tourism brand. By the end of 2010 the transborder agri-tourism cluster of Euroregion "Dnipro" included more than 300 natural, historical and cultural and archaeological sites. A number of "green" rings and radial routes — hiking, cycling, and horse-riding, which run through the territory of the cluster localisation, have been developed [9].

Thus, main efforts towards transborder cooperation between the countries are aimed at developing social, information and border infrastructure; development of transport networks; scientific and cultural cooperation; exchange of experience between the local executive authorities; environmental protection, etc. However, a cluster form of cooperation in the transborder space has not received a proper extension in Ukraine, and is only a stage of development.

Since formation of clusters reflects the "economic profile" of the territory and is an objective result of the development of a particular business in a given territory, each region is characterised by its directions in implementing cluster initiatives.

Strategy of the socio-economic development of Kharkiv region [25] defines the following scientific and industrial clusters in the regional economy (Table 3).

Table 3. Scientific and industrial clusters in the economy of Kharkiv region

No.	Name of the cluster	Measures to implement the project of the cluster creation
1	Cluster of power engineering	Restructuring and reorganisation of individual enterprises participating in the cluster. The state order for part of the cluster final product.
2	Innovation cluster of the aircraft industry	Restructuring and reorganisation of individual enterprises participating in the cluster. The state order for part of the cluster final product.
3	Scientific and production innovation cluster of the rocket and space complex	Creation of an associated structure of the cluster participants. Restructuring and reorganisation of individual enterprises. Implementation of the results of new research and developments.
4	Research and production innovation cluster of military (armoured) vehicles	Creation of a vertically integrated structure. Restructuring and reorganisation of enterprises. The state order for the cluster product.
5	Research and production cluster of agricultural engineering	Creation of an associated structure of the cluster participants. Restructuring and reorganisation of individual enterprises. Conclusion of interregional cooperation agreements.

Source: [25]

One of the priority clusters in the economy of Kharkiv region is a cluster of power engineering. On 02.05.2015 Kharkiv Regional Center for Investment and Development initiated the founding meeting of the Coordinating Council of the cluster of Power Engineering, where the draft Strategy of its development was adopted, which the following priorities were defined in:

- renewal of fixed assets of enterprises;
- creation of competitive new equipment and technologies;
- introduction of a system of personnel training and skills development;
- creation of a network of engineering centres;
- networking — development of international cooperation [26].

On 02.12.2009 the ICT cluster "Kharkiv-IT" was formed and has been effectively functioning since then. It is not a legal entity and the organization of its work is carried out by the working group under the leadership of the cluster Coordinating Council. Fig. 2 presents the group of the cluster participants.

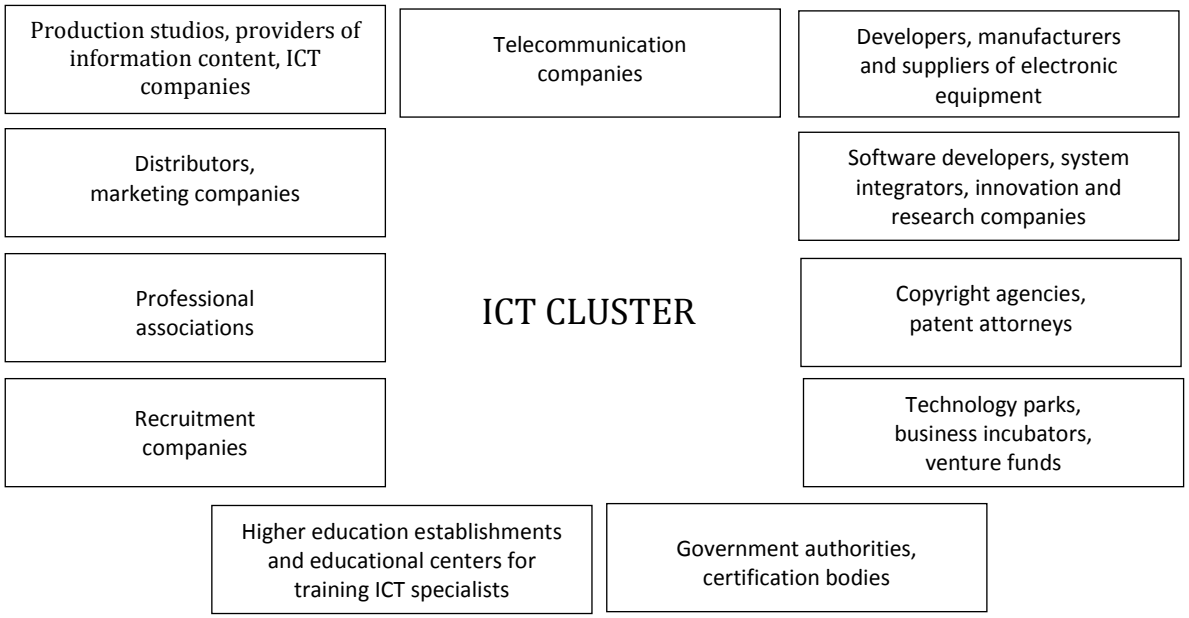

Fig. 2. Types of enterprises and organizations belonging to the ICT cluster "Kharkiv-IT"
Source: [27]

In 2012 the importance of the cluster was confirmed by the decision of the Council of Domestic and Foreign Investors at Kharkiv Region State Administration, according to which the cluster of information and communication technologies "Kharkiv-IT" was included in the list of priority clusters defining the prospects of the region development.

The practice of implementing cluster initiatives in Ukraine shows that in most cases the initiators of clustering are heads of enterprises and organisations working in the relevant field of economic activity, as well as territorial and central executive authorities interested in cluster development. The formed clusters are intended to contribute to: attraction of investments, encouragement of research activity, development of small business through use of the advanced technologies, entrance of products to international markets and enterprises and entering the strategic cooperation network.

Comparative analysis of prospects for development of clusters in Poland and Ukraine

The main determinants of the cluster development in Poland and Ukraine as well as their evaluation are presented in Table 4, while the results of comparative analysis of perspectives for development of clusters in Poland and Ukraine are presented in Table 5.

Table 4. The main determinants of the cluster development in Poland and Ukraine. Scale of the positive impact of the determinant: 0 – no impact; 1 – an appreciable but little impact; 2 – a modest impact; 3 - a significant, positive impact; 4 - a major positive impact; 5 – an excellent positive impact

Determinants	Perspectives for development of clusters in Poland	Impact	Perspectives for development of clusters in Ukraine	Impact
Political	Presently, the political situation in Poland is not stable enough to promote the cluster initiatives. Analysts of the Polish political scene predict a retreat of pro-market towards centralisation of decision-making process. There are serious reasons for concern that the current government, formed by Law and Justice (PiS), can launch the political model where there is no place for regional cooperative relations. Greater importance is given to the so-called national values versus values of the European Union, centralisation of power in the hands of one party and restoring control of regional policy from the level of central administration.	1	The political situation in Ukraine is very unstable at the moment, which is aggravated by the military aggression on the part of Russia. The present government does not take necessary measures in the direction of preparation and adoption of normative legal acts on stimulating the development of cluster structures in Ukraine.	0
Economical	Economic conditions for the implementation of the cluster policy are unclear. Polish government, except declarations, does not create real economic conditions enabling the development of cluster initiatives. The only promotion for clusters are promises that the National Key Clusters will receive extra points in competitions for funding. There are no preferences for cluster coordinators, nor for the cluster members. There is a lack of economic incentives, such as tax cuts for activities contributing to the development of the cluster, or discounts of state-related labor costs. However, there is a strong pressure of companies to facilitate the tax system and remove barriers for entrepreneurship.	2	On the one hand, the economic conditions for realisation of the national cluster policy are extremely unfavorable at the moment because of the deep complex crisis in Ukraine. On the other hand, there is no alternative to the development of cluster structures in the country regions, because only such an approach can provide an effective restructuring of the economy. This discrepancy leads to the fact that the processes of cluster formation in the country occur spontaneously, without their proper organisation by the state and in absence of any support and economic incentives of their development. Perspectives for the development of the economic situation in Ukraine and, in particular, the conditions of the cluster policy development, are difficult to predict, because they are greatly affected by the political situation in the country.	1
Financial	The EU's financing policy of supporting cooperation between science and	4	The state policy of funding science in the country does not contribute	1

Determinants	Perspectives for development of clusters in Poland	Impact	Perspectives for development of clusters in Ukraine	Impact
	industry has a positive effect, indirectly, on the cluster funding mechanisms in Poland. Most calls for proposals prefer the projects prepared by consortia of the enterprises and R&D institutions. However, the promotion of cooperation of science and industry does not mean preferences for clusters. Any consortia of R&D institutions and companies can apply for the grants, and the clusters do not receive any respectful privileges. Although Poland has not created any national sources for development of clusters, the impact of the EU funds on the development of consortia of industrial and academic partners will significantly contribute to the development of clusters.		to the development of cluster structures. Moreover, the policy of reducing scientific research funding pursued by the government breeds up concern. The high level of monopolisation of the Ukrainian economy and the presence of oligarchs in the national government leads to the fact that the financial and economic policy pursued by them does not contribute to cooperation between science and industry because of the lack of interest in such processes.	
Technological	Clusters in Poland have been just equipped with modern technological infrastructure, including ICT facilities, enabling their development and expansion. This applies to modern buildings, technology lines, laboratory equipment, tools and devices, enabling the applied scientific research useful for business.	5	Clusters in Ukraine are very poorly equipped with modern technical infrastructure. This is particularly true in terms of modern laboratories, industrial machinery, tools and equipment, which adversely affects the conduct of applied research.	1
Societal	Cooperation within the cluster requires a high social capital, which means the social acceptance of building partnerships, trust, dissent and tolerance, respect for partners and skills for tasks' division and creation of a joint development prospects for the cluster as a whole. Level of social capital in Poland is low and unfortunately in recent months has decreased even more. Polish society is characterised by mutual mistrust, which is not conducive to building a broad cooperative relations.	2	Public recognition of partnerships within the clusters is at a low level. The level of social capital in Ukraine is low as well. In general a low level of transparency and trust between potential participants in the cluster, and, in particular, a very low confidence in the authorities can be noticed.	1
International	EU policy offers many incentives for building international cooperations of clusters as the whole and for cooperation of cluster members, especially there are many facilitations and incentives for consortia of industry and R&D. At most EU competitions reward the international cooperation,	4	The state policy on establishing international cooperation of Ukrainian clusters with foreign partners does not contribute to this process. Cooperation between domestic cluster structures and foreign partners on the basis of personal	1

Determinants	Perspectives for development of clusters in Poland	Impact	Perspectives for development of clusters in Ukraine	Impact
	if not just clusters as main actors, but also the projects of collaboration of companies and research institutions (e.g. within the Horizon 2020 Programme), or cooperation of local government administration, R&D, enterprises and non-governmental organisations (e.g. within the InterReg Programmes). The European Commission expects cooperation of partners from at least three countries, including partners from non-EU countries as well. This means that the impact of the strategy of Europe 2020 and European incentives for building international cooperation significantly contributes to the development of clusters in Poland.		efforts and contacts is possible.	
Readiness of entrepreneurs to cooperate in clusters	Polish entrepreneurs are very interested in joining cooperative networks. They recognise in clusters chances to extend the network of subcontractors, including R&D institutions, increase knowledge and develop technology on the basis of international contacts.	5	Ukrainian entrepreneurs are interested in joining the cluster structure and are willing to participate in them.	3
Readiness of R&D institutions to cooperate in clusters	Readiness of the Polish R&D institutions to engage in cluster activities is modest. The system of incentives for R&D institutions to stimulate their participation in cluster initiatives is insufficient. The unsatisfactory incentives are also in relation to foreign cooperation, join consortia of industry and scientific research institutions and to take part in projects financed from European sources.	3	The readiness of Ukrainian R&D institutions to be engaged in the cluster activities is not high. The system of incentives for R&D institutions to stimulate their participation in cluster initiatives is insufficient. Also for today there has not been attained enough experience in such participation. It is possible to speak only about individual R&D institutions in Ukraine capable of participating in joint projects.	1

Source: Authors'

Table 5. Comparative analysis of perspectives for development of clusters in Poland and Ukraine

Determinants	Perspectives for development of clusters in Poland				Perspectives for development of clusters in Ukraine					
Political										
Economical										
Financial										
Technological										
Societal										
International										
Readiness of entrepreneurs to cooperate in clusters										
Readiness of R&D institutions to cooperate in clusters										
Weight	5	4	3	2	1	1	2	3	4	5

Source: Authors'

Conclusions: the factor that is most conducive to the development of cooperation between Polish and Ukrainian clusters is readiness and determination of entrepreneurs of both countries. According to the authors of this article, members of clusters in Poland and Ukraine cannot count on the political support of their governments, despite the many empty declarations of cooperation of politicians.

Summary: Areas and direction of Polish-Ukrainian cooperation of clusters.

The possibilities of cooperation within the European projects

Horizon2020 Programme

Ukraine is one of the 13 Associated Countries with the privilege to participate in Horizon 2020 Programme, which is governed by Article 7 of the Horizon 2020 Regulation. Legal entities from Associated Countries can participate under the same conditions as legal entities from the Member States. Association to Horizon 2020 takes place through the conclusion of an International Agreement.

As of 1 December 2015, the following countries are associated to Horizon 2020:

- Iceland
- Norway
- Albania
- Bosnia and Herzegovina
- the former Yugoslav Republic of Macedonia
- Montenegro
- Serbia
- Turkey
- Israel
- Moldova
- Switzerland
- Faroe Islands
- Ukraine.

Given that the EU does not recognise the illegal annexation of Autonomous Republic of Crimea and the City of Sevastopol, under the terms of the Horizon 2020 Association Agreement with Ukraine, legal persons established in the Autonomous Republic of Crimea or the city of Sevastopol are not eligible to participate. Should the illegal annexation of the Autonomous Republic of Crimea and the City of Sevastopol end, the Agreement will be revised accordingly.

General clarifications and up-date on signature of the Horizon 2020 Association Agreement with Ukraine were made on 22.04.2015.

Case study: EcoDesign Exploring New Value Chains (EDEN), project of H2020. The EDEN project will connect four different clusters and an industrial federation from different parts of Europe, disposing of different resources, tools and instruments. Groups of SMEs will be supported to collaborate and create international, cross-cluster networks. The separate value chains already existing in each industry are aimed to be integrated under cross-sectoral collaboration paradigm. This closer cooperation will let them create the comparative advantage on the intersections between existing industries. The development of industrial areas, increasing amounts of produced garbage and shrinkage of natural resources are among major problems EDEN tackles, so does it with a challenge of people's growing demand for creative new products. All the planned actions are intended to be replicable so that the potential large-scale solutions could be created and its future impact could be enhanced ad infinitum. As the whole concept will be based on a joint innovation support standard, all of these activities will have a significant positive influence on the European SMEs innovative potential and the environment.

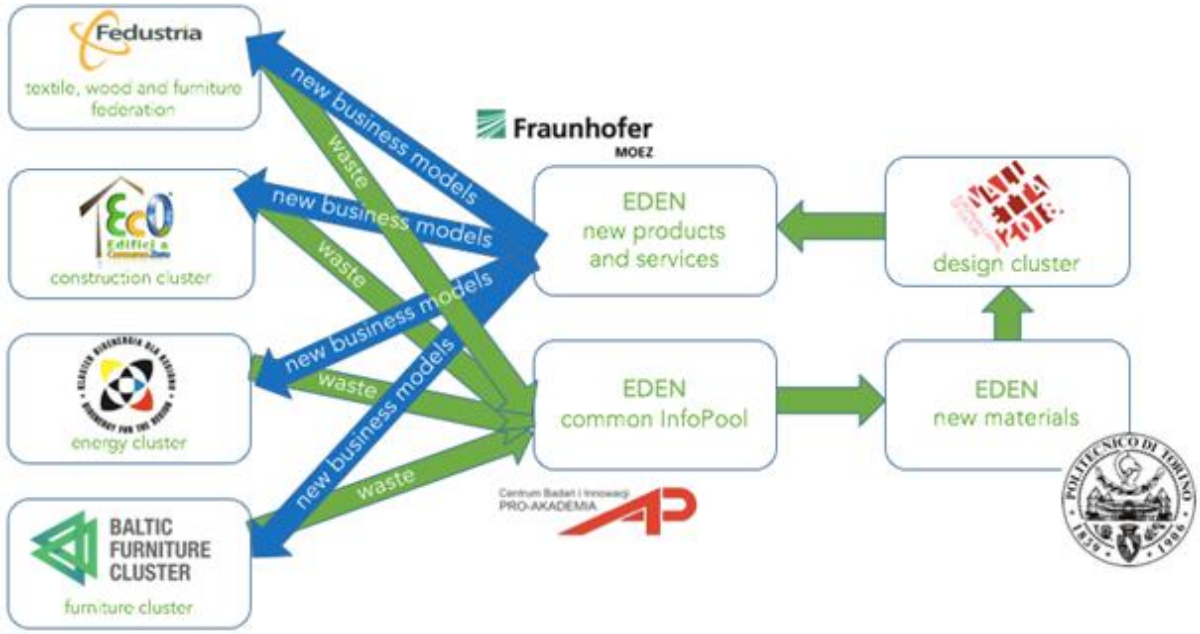

Fig. 3. EDEN concept for new value chain generation as the result of European clusters" cooperation
Source: Authors'

EDEN main focus lies on exploring the existing circular economy potentials at the level of over 2000 SMEs participating in the EDEN member clusters. Its overriding idea was to use the eco-design as an accelerating and propelling centerpiece, predominantly due to its representatives' extraordinary capability of creating new applications for any materials. As presented in Fig. 3, the coordinators of textile, wood, furniture, energy and construction clusters will collect information on all forms of waste resulting from operations of SMEs in their networks using a standardized, common approach. Information collected will concern for instance waste type, monthly mass and volume flows, real non-product output costs, elementary composition, ignitability, corrosiveness, reactivity, toxicity. All these data will be collected and processed in the online EDEN common InfoPool, which will be the main source of information on the existing potentials of participating enterprises. The outcomes will be examined by the waste recycling specialists from the academic field who will present the ideas on utilising them to the design cluster. In some cases it will be even possible to turn raw waste directly into new products, avoiding costly recycling processes. The designers will propose new products that will be applied with new business models to suitable cluster, propelling intra-cluster and cross-cluster waste-as-a-feedstock exchange. The Fig. 4 shows the concept of design of new composite material, useful in different kind of manufacturing, properly to clusters specific.

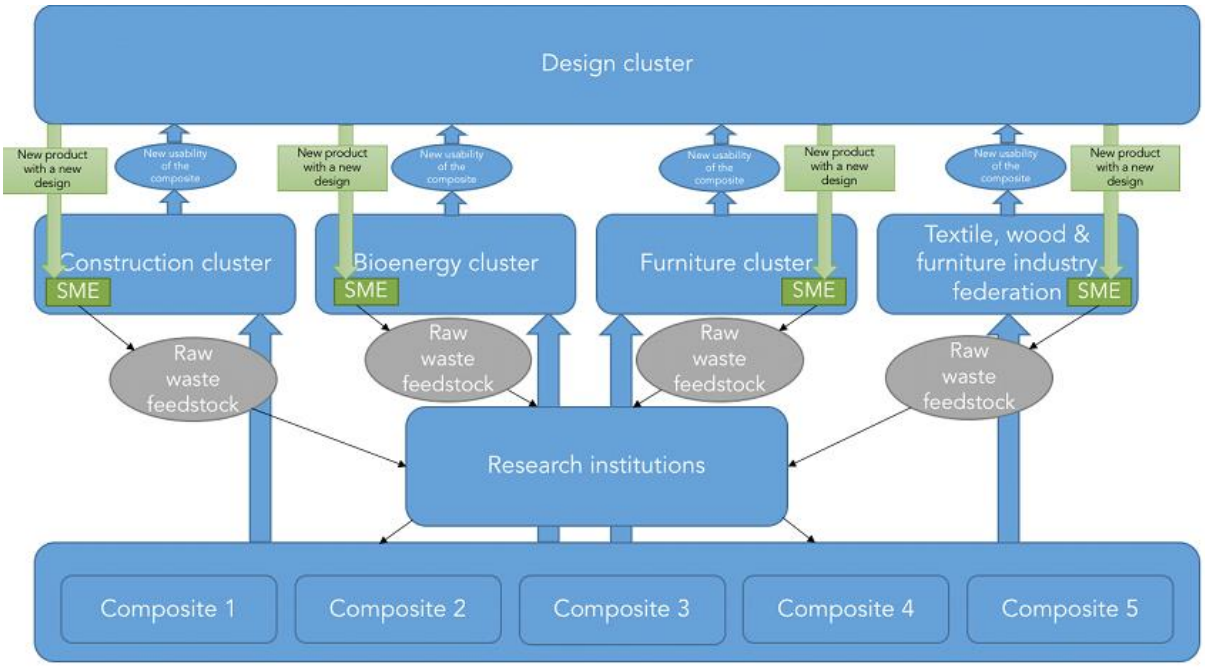

Fig. 4. EDEN concept for design of new composite materials and products based on raw waste feedstock
Source: Authors'

As the clusters and SMEs will collaborate within the EDEN project, all of the tasks carried out are practical and have a specific, concrete business dimension. Thanks to the international cooperation of clusters from different sectors of the economy, the new products based on recycling and processing their own waste will be created.

The above described H2020 project EDEN with participation of clusters from EU countries can be an good practice and a "light-house" for Polish-Ukrainian clusters cooperation.

Europe-Aid Programmes

Interesting example of Europe-Aid Programmes can be DCFTA SME Direct Support Facility Programme, addressed to the private sector in Georgia, Moldova and Ukraine, particularly through lending to small and medium-sized enterprises (SMEs). Timeframe of the programme: 2014-2026; budget: EUR 10.22 million. The project aims to blend funds from the EU and the European Bank for Reconstruction and Development in order to provide financing and technical assistance to the SME sector and to improve conditions for SMEs lending.

The DCFTA SME Direct Support Facility aims to achieve the following:

- To improve access to finance for local SMEs in the region.
- To mitigate the shortage of long-term financing.
- To provide quasi-equity financing that is not available at all in most target countries
- To provide long-term local currency financing.
- To help SMEs identify quality capital investment projects, assist in successful implementation.
- To improve governance structure of SMEs and introduce SMEs to best practices.
- To help strengthen the ability of financial intermediaries to finance SMEs through co-financing.
- To help develop local financial markets in view of sustainable and market-based principles.

Eastern Partnership Programme

One of the programmes worth of attention is EBRD Women in Business, which aims to raise the issue of women's entrepreneurship in broader development plans, addressed to the following countries: Armenia, Azerbaijan, Belarus, Georgia, Moldova and Ukraine. Timeframe of the programme: 2015-2022; budget: EUR 5.035 million.

Women entrepreneurs are concentrated in lower value-added sectors of the economy (typically in services), and women-led small and medium-sized enterprises (SMEs) in Eastern Partnership countries are often confined

to the informal sector of the economy. Consequently, access to finance through formal institutions is a key challenge for women-led businesses in the region. The programme aims to improve access to finance for women-led SMEs as well as business development know-how.

The objective of the programme is to promote women's entrepreneurship and, more broadly, women's participation in business by supporting women-led enterprises with access to funding, particularly:

- Supporting women's SMEs in accessing finance for their sustainable growth and job creation
- Developing sustainable financial products suitable specifically for women-led SMEs
- Assisting women's SMEs to access advice and know-how.

Although the programs outlined above are not addressed precisely for Polish or Ukrainian clusters, but in the framework of each of them Clusters can develop a project that will fit into the general objectives of the programmes.

An interesting example of stimulation of international clusters' cooperation can be the TREC Danube – Transnational Renewable Energy Cluster Danube, funded by German Federal Ministry for Education and Research. TREC Danube is a transnational network of regional clusters in the field of renewable energy, energy systems and bioeconomy. The clusters from Ukraine and Poland participate in the initiative. The TREC is a platform for R&D driven innovations in energy and environmental technology markets and it tries to build up strong consortia for EU-Horizon 2020 calls basing on interlinking and focusing our profound competencies from the regions.

Possibilities of bilateral cooperation of cluster members, with the support of cluster coordinator

It seems that the bilateral cooperation between the Polish and Ukrainian clusters has little chances for development in the near future. Polish clusters are in the phase of consolidating the national and regional networks and strengthening the internal structure in order to be a part of EU eco-innovation system. On the other hand, the clusters of Ukraine have just begun the processes of building the national eco-innovation system. There is no strong external incentives to go beyond their own cooperative relation and to start looking for bilateral partners in Poland or in Ukraine. At the present stage of development, Polish and Ukrainian clusters do not notice the benefits of economic cooperation with the other side of the border.

As shown in the Table 5, the strongest determinant for cooperation between clusters is the interest of entrepreneurs themselves, but it is not enough for clusters as a whole. Cluster is a network of companies, research institutes, local administration and business environment institutions and all these partners should have their particular reasons for international cooperation. The Table 5 shows as well that there is an imbalance in readiness to cooperate: the potential of bilateral cooperation between Polish and Ukrainian clusters is determined by the state of development of Ukrainian clusters.

Possibilities of creating joint projects of Polish and Ukrainian clusters in third countries markets

The analysis of the practice of creating cluster structures in Poland and Ukraine shows that both countries can take the initiative of establishing joint cluster projects in third countries in the following fields of economy:

- renewable energy sources and alternative power engineering;
- information and communication technologies;
- aircraft industry;
- production and processing of agricultural products and food production.

The Bioenergy for the Region Cluster (B4R) (Research and Innovation Center Pro-Akademia is the managing institution of the B4R Cluster) was created in the field of renewable and alternative power engineering in Lodz (Poland). A cluster for alternative fuels production, including the hydrogen, (the managing institutions are SE "GIPROKOKS" and Research Centre of Industrial Problems of Development of NAS of Ukraine) operates in Kharkiv (Ukraine). In addition to the above mentioned, the following clusters could take part in the given cluster project in third countries (Bulgaria, Kazakhstan, Belarus, Moldova, Azerbaijan, Georgia, Armenia): Lower Silesian Eco-Energetic Cluster EEI (managed by Foundation CEDRES), Lublin Eco Energy Cluster (managed by Lublin Development Foundation), Subcarpathian Renewable Energy Cluster (managed by the Association "Subcarpathian Ecoenergetics") (Poland).

Since 2009 in Kharkiv (Ukraine) the ICT cluster “Kharkiv-IT” (managed by Kharkiv National University of Radioelectronics) comprising 25 members, among which are IT-companies, higher educational establishments and research institutions of the city, has been functioning in the domain of information and communication technologies. A number of clusters operate in the given field in Poland as well, namely: Interizon Pomeranian ICT Cluster (Gdańsk University of Technology), ICT West Pomerania Cluster (managed by the Association of ICT West Pomerania Cluster), Mazovian ICT Cluster (managed by the Association of Economic and Social Development “Wiedza”). The above mentioned Ukrainian and Polish ICT clusters can initiate the creation of joint cluster projects in third countries (Bulgaria, Slovakia, Slovenia, the Czech Republic, Kazakhstan, Belarus).

The aircraft industry cluster “Aviation Valley” (managed by the Association of the Group of Entrepreneurs of the Aviation Industry “Aviation Valley”) is situated in the South-Eastern part of Poland. The ICT cluster “Subcarpathian Aviation Cluster” (managing institution — Association B-4), which operates in the sector of light and ultra-light aircraft, is also located in Poland. In Kharkiv (Ukraine) there was also created a cluster of the aircraft industry, which comprises industrial enterprises, the main of which is “Kharkiv State Aircraft Enterprise” (managing institution), educational establishments (e.g. National Aerospace University “Kharkiv Aviation Institute”) and institutions for applied sciences. The mentioned Ukrainian and Polish clusters can take the initiative of creating specialised cluster projects in third countries (Czech Republic, Slovakia, Slovenia).

A cluster for production and processing of agricultural products and the production of food has been created in Kharkiv (Ukraine). It includes enterprises of agricultural, food and processing industry of the region, establishments of agricultural science and education — V. Dokuchaev Kharkiv National Agrarian University (managing institution), Kharkiv State Academy of Zooveterinary Medicine of NAS of Ukraine, Institute of Animal Science and others. The Organic Food Valley Cluster (the coordinator is Institute of Soil Science and Plant Cultivation — State Research Institute) functions in Puławy (Poland). The members of the cluster are companies that have the potential and experience in ecological production. These Ukrainian and Polish clusters can also initiate the establishment of joint projects in third countries (Bulgaria, Moldova, Kazakhstan).

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NOVEL SILVER COMPLEXES WITH POPULAR NON-STEROIDAL ANTI-INFLAMMATORY DRUGS

Abstract
Non-steroidal anti-inflammatory drugs (NSAID) are class of drugs with antipyretic, analgesic and anti-inflammatory properties. They have also exhibited anti-tumor activity. Even though the mode of their anti-inflammatory activity action is well understood, they exhibit significant adverse effects. Metal complexesation with NSAID may be a promising option for side effects reduction. The novel silver complexes with commonly used non-steroidal anti-inflammatory drugs: ibuprofen, naproxen, mefenamic acid and ketoprofen, were synthesized and characterized by elemental analysis, IR- spectroscopy and thermal decomposition techniques. Coordination of ligands to the silver ions was confirmed by IR spectroscopy. IR data clearly indicate that NSAID anions are bonded in a monodentate mode. The thermal behavior of complexes was studied by TG, DTG and DTA methods in air. Upon heating all compounds decomposed progressively to silver oxide, which was the final product of pyrolysis.

Key words
Non-steroidal anti-inflammatory drugs, metal complexes, FTIR, thermal investigations

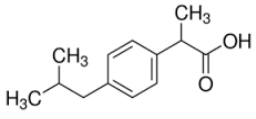
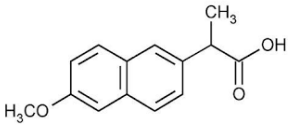
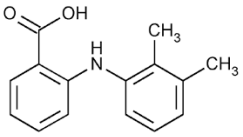
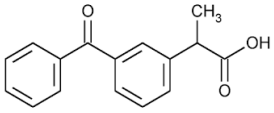
Introduction

Non-steroidal anti-inflammatory drugs are among the oldest [1] and most popular drugs in contemporary medicine [2, 3]. The precursors of non-steroidal anti-inflammatory drugs were salicylic acid and salicylates, isolated from natural sources, have long been used as medicines. The acid was chemically synthesized in 1860 and was further used as an antiseptic, an antipyretic, and an antirheumatic agent. Almost 40 years later, aspirin was developed as a more palatable form of salicylate. Soon after, several drugs having similar action to aspirin were discovered, and the whole group was named the 'aspirin-like drugs'. It was growing quite rapidly and more recently got a new name i.e. the nonsteroidal anti-inflammatory drugs (NSAID)[4]. In 1971 Vane showed that NSAID hampers biosynthesis of prostaglandins (PG) by inhibiting activity of an enzyme – cyclooxygenase (COX) and suggested mechanism of their action [4-5]. Further investigations lead to the discovery of two isoforms of COX. COX-1 is a constitutive enzyme which prompts PG synthesis further protecting stomach and kidney. On the other hand, COX-2 is induced by inflammatory factors, like cytokines, and produces PG that contribute to the pain and inflammation swelling [6-7]. Therefore, drugs which are selective COX-2 inhibitors should show pronounced anti-inflammatory action without side effects on the kidney and stomach. Additionally, selective inhibitors have much wider therapeutic potential including ovulation and premature labors. Several NSAID delay progress of the Alzheimer's disease [8-9]. The quite recently discovered protective action of NSAID on cancer follows from their action on COX-2 [10-15]. Unfortunately, the widely prescribed NSAID to control pain and inflammation are gastrointestinal toxic and may lead to skin allergies as well as cardiovascular and renal diseases in particular when administrated over a long time and without the usual care [16-20].

It is quite well recognized, that several transition metal complexes with non-steroidal drugs are more effective and show lower toxicity, than their parent drugs [1,21-22]. Recently Banti and Hadjikakou documented anti-cancer activity of metal complexes with non-steroidal anti-inflammatory drugs [23]. Silver ion is also known as antibacterial and antifungal agent with low toxicity as compared to the other transition metal [24]. Moreover, silver complexes containing various ligands exhibit selectivity against variety of cancer cells [25]. In this respect, coordination chemistry is an useful method to improve the overall efficiency of NSAID and in the same time reduce their well-recognized side effects .

This paper describes synthesis, spectroscopic and thermal properties of silver complexes with four commonly used in medicine NSAID [26-33], namely ibuprofen (ibup), naproxen (napx), mefenamic acid (mef) and ketoprofen(ket) (Table 1).

Table 1. The structural formulae and popular application of chosen NSAID

NSAID	Chemical formula	Typical use
Ibuprofen		• pain • inflammation • headache • toothache
Naproxen		• arthritis • ankylosing • spondylitis • tendinitis
Mefenamic acid		• menstrual pain
Ketoprofen		• rheumatoid • osteoarthritis • acute, chronic pain

Source: own compilation on the basis of [26-33]

Materials and measurements

Pure ligands were received as gift from Polish pharmaceutical companies: Pabianickie Zakłady Farmaceutyczne Polfa S.A., Medana Pharma S.A.and Emo-farm Sp. z o.o.; EtOH p.a. was purchased from Aldrich, MeOH from Lab-Scan, all other chemicals were from POCh- Gliwice.

All complexes were obtained according to similar procedures. The first step of synthesis was preparation sodium salt of particular ligand by dissolution of ibuprofen, naproxen, ketoprofen or mefenamic acid (1 mmol) in 50 ml freshly precipitated NaOH aqueous- ethanol solution (1:1) (0,02 mol· L^{-1}). The mixture was heated up to 60°C and added to aqueous solution of silver nitrate (1 mmol in 25 mL). The reaction mixture was kept in 60°C for 2 hours. After several days the solid precipitates were isolated by filtration, washed with hot water and dried on air.

The composition of complexes was determined by chemical and elemental analyses. The contents of N, C and H were established using automatic Carbo-Erba analyser in a pure oxygen over V_2O_5 catalyst. The amount of metal was determined by complexometric titration of a mineralized sample. An open system with nitric(V) acid was applied. IR spectra were recorded on FTIR-8501 Shimadzu spectrophotometer over 4000–400 cm^{-1} range using KBr pellets. Thermal stabilities were studied by TG and DTG techniques with the Netzsch TG 209 apparatus. Samples (10mg) were heated in ceramic crucibles up to 1000°C, at a heating rate 10˚C min^{-1} in air atmosphere. The solid decomposition products were identified on TG and DTG curves and further confirmed by the X-ray powder diffraction of sinters (Siemens D-5000 diffractometer, graphite monochromatised CuK_α radiation).

Results and discussion

Empirical formulae of complexes augmented by relevant analytical data are summarized in Table 2. All synthesized complexes were obtained as highly crystalline powders. The latter was unequivocally confirmed by X-ray diffraction. They were stable in air and practically insoluble in water but quite well soluble in popular polar organic solvents, like EtOH, MeOH and acetone.

Table 2. Empirical formulae of complexes augmented by relevant analytical data

Complex	Analysis: found (calculated) /%			
	Ag	N	C	H
Ag(ibup)	34.36 (34.45)	-	49.77 (49.86)	5.50 (5.48)
Ag(napx)	32.00 (31.99)	-	49.58 (49.88)	3.78 (3.87)
Ag(mef)	31.00 (30.98)	4.15 (4.02)	52.08 (51.75)	4.05 (3.99)
Ag(ket)	29.44 (29.87)	-	53.06 (53.21)	3.70 (3.64)

Source: Author's

Coordination of ligands to the silver ions was confirmed by IR spectroscopy. In particular, characteristic bands from the valence vibration of carboxyl group were not observed. On the contrary, there appeared bands from asymmetric (1567-1585 cm^{-1}) and symmetric (1375-1384 cm^{-1}) vibrations of dissociated COO^- group. These bands are affected by the coordination of ligands to silver ions. According to Nakammoto criteria [34], the separation $\Delta\nu=\nu_{as}(OCO)-\nu_{s}(OCO)$ and the direction of the band shifts in comparison to corresponding values in parent sodium salt characterize the nature of metal – carboxylate bond. The batochromic shifts of asymmetric (ν_{as}) and hypsochromic of symmetric (ν_s) frequencies were observed. All relevant data are summarized in Table 3. They clearly indicate, that carboxylate groups in all synthesized compounds coordinated as monodentate. The IR spectra of synthesized complexes are collected on Fig. 1-4.

Table 3. Principal IR bands (cm^{-1}) for carboxylate groups in synthesized complexes and sodium salts of ligands

Compound	ν_{asym}	ν_{sym}	$\Delta\nu = \nu_{asym} - \nu_{sym}$
Na(ibup)	1548,7	1411,8	136,9
Ag(ibup)	1567,9	1384,7	183,2
Na(napx)	1547,0	1407,1	139,9
Ag(napx)	1564,7	1394,5	170,2
Na(mef)	1580,0	1380,0	200,0
Ag(mef)	1584,7	1375,4	209,3
Na(ket)	1567,0	1394,0	173,0
Ag(ket)	1577,5	1384,7	192,8

Source: Author's

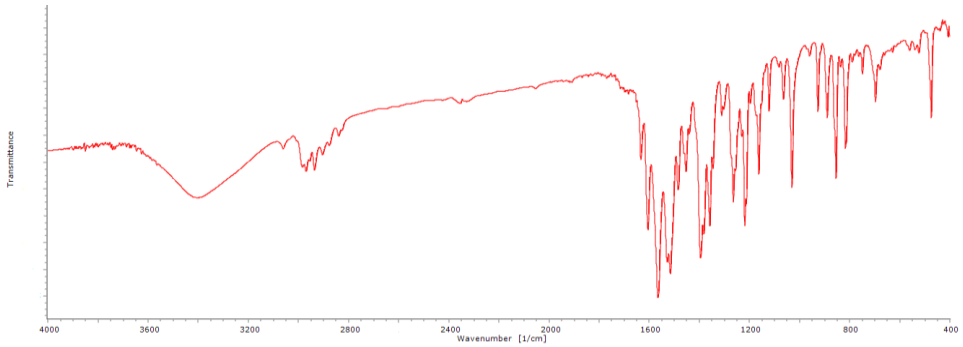


Fig.1. IR spectra of Ag(ibup)
Source: Author's

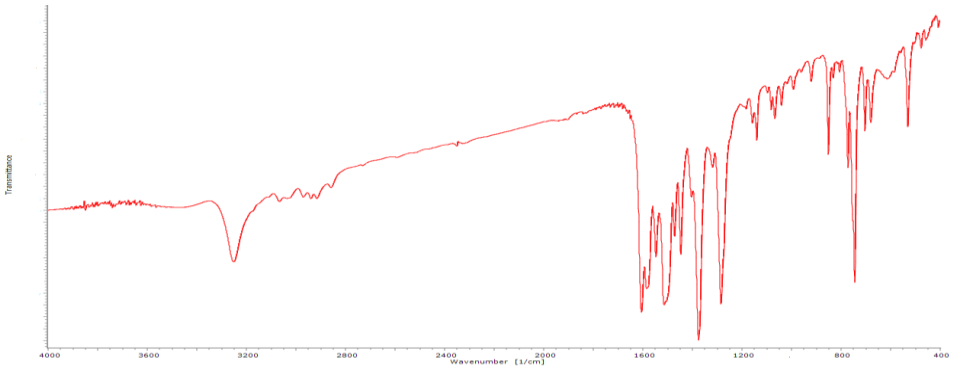


Fig.2. IR spectra of Ag(napx)
Source: Author's

Additionally, mefenamic and ketoprofen anions have amine and carbonyl group, respectively. Potentially they can be available for coordination. The characteristic IR bands of these groups in free ligands are very close to those observed in silver complexes. That indicates, that neither the NH group in Ag(mef) nor CO in Ag(ket) participate directly in coordination.

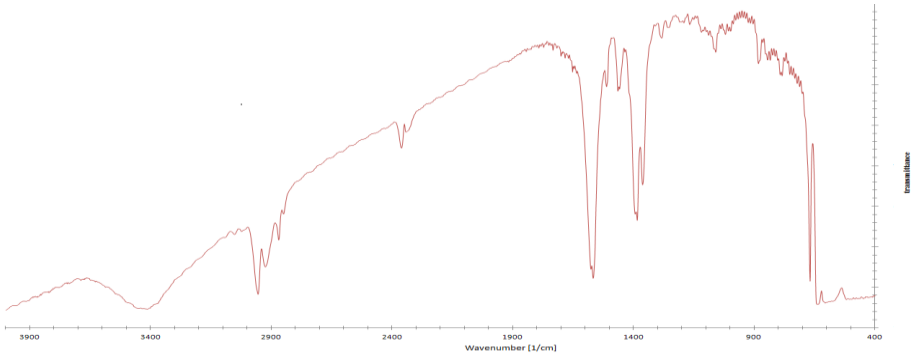


Fig.3. IR spectra of Ag(mef)
Source: Author's

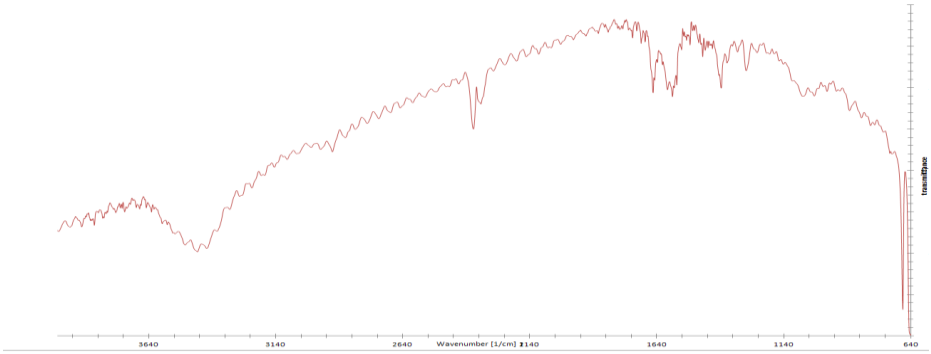


Fig.4. IR spectra of Ag(ket)
Source: Author's

The data obtained from TG, DTG curves supported by chemical and X-ray diffraction analysis are collected in the Table 3. The thermal decomposition curves of complexes are shown on Fig. 5-8.
The thermal decomposition of synthesized complexes is quite similar. Pyrolysis is a two-stages process for all complexes. Almost all compounds are thermal stable up to 180°C, only for Ag(ket) higher thermal resistance was detected (220°C). Further increase of temperature (in ranges 180-550°C) results in high mass loss (*ca.* 50%) caused by organic ligand decomposition. Further heating in the terminal step of pyrolysis leads to metallic silver formation. The whole mass loss 65,5% for Ag(ibup), 68% for Ag(napx), 69% for Ag(mef) and Ag(ket) is in good agreement with calculated amounting to 65,55%, 68,01%, 69,02% and 70,13% respectively for ibuprofenato, naproxenato, mefenamato and ketoprofenato complex.

Table 3. Thermal decomposition data of complexes in air

Compound	Ranges of decomposition /°C	Mass loss /%		Intermediate and final product
		found	calculated	
Ag(ibup)	180–250	47.5	46.70	AgOAc
	250–400	18.5	18.85	Ag
Ag(napx)	180–480	51,0	50.50	AgOAc
	480–700	17.0	17.51	Ag
Ag(mef)	180–550	52.0	52.06	AgOAc
	550–710	17.0	16.96	Ag
Ag(ket)	220–480	53.0	53.78	AgOAc
	480–640	16.0	16.35	Ag

Source: Author's

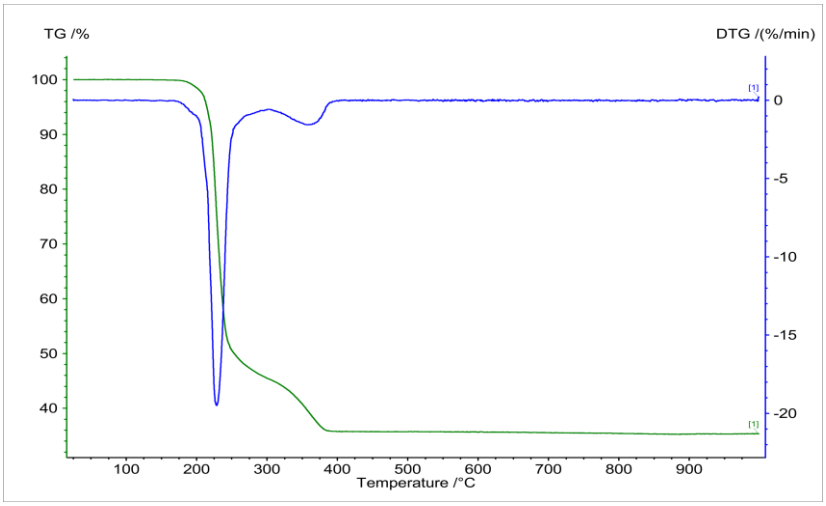


Fig. 5 Thermoanalytical profiles for Ag(ibup)
Source: Author's

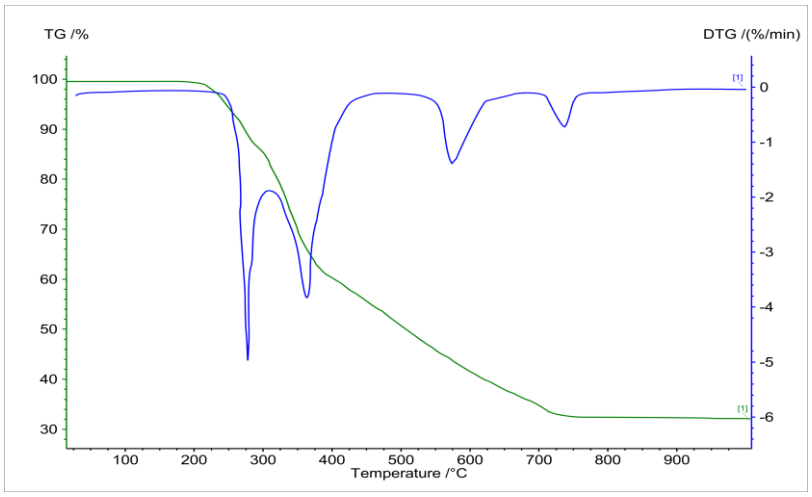


Fig. 6. Thermoanalytical profiles for Ag(napx)
Source: Author's

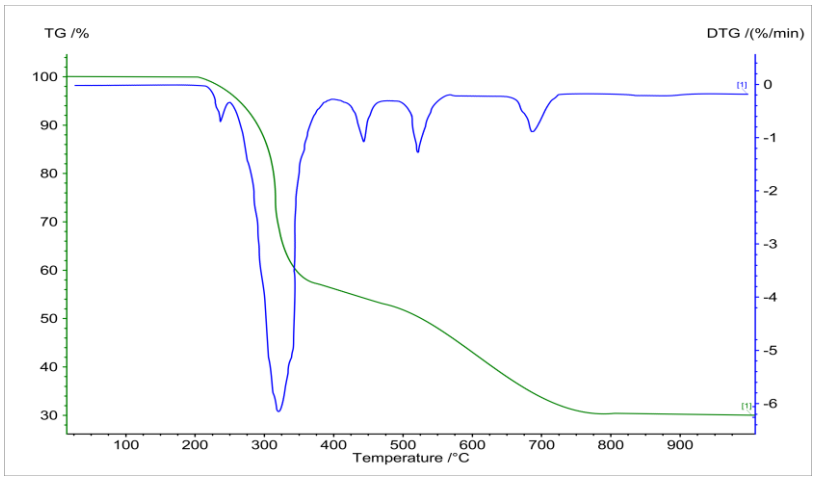


Fig. 7. Thermoanalytical profiles for Ag(mef)
Source: Author's

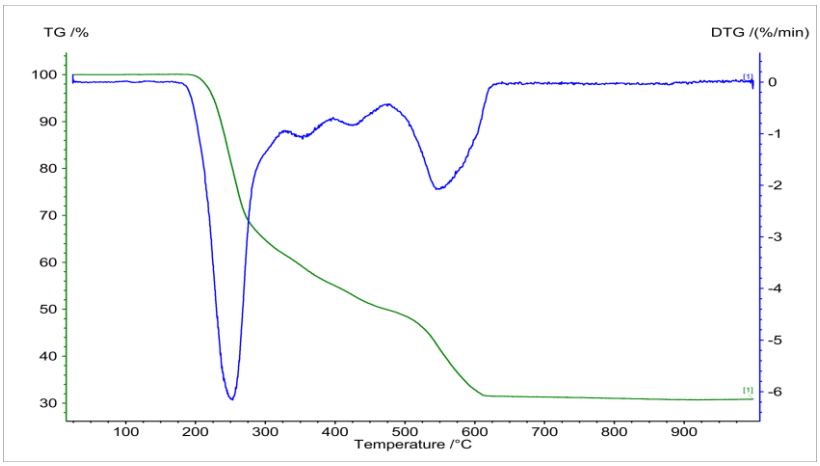


Fig. 8. Thermoanalytical profiles for Ag(ket)
Source: Author's

Presence of silver, as a final product of thermolysis, was confirmed by powder X-ray diffraction of sinters. They were prepared by heating complexes up to relevant temperature (from TG curve). The prominent XRD reflections (Fig. 9 and 10) compared with CCDC model corroborated, that the product is metallic silver [35].

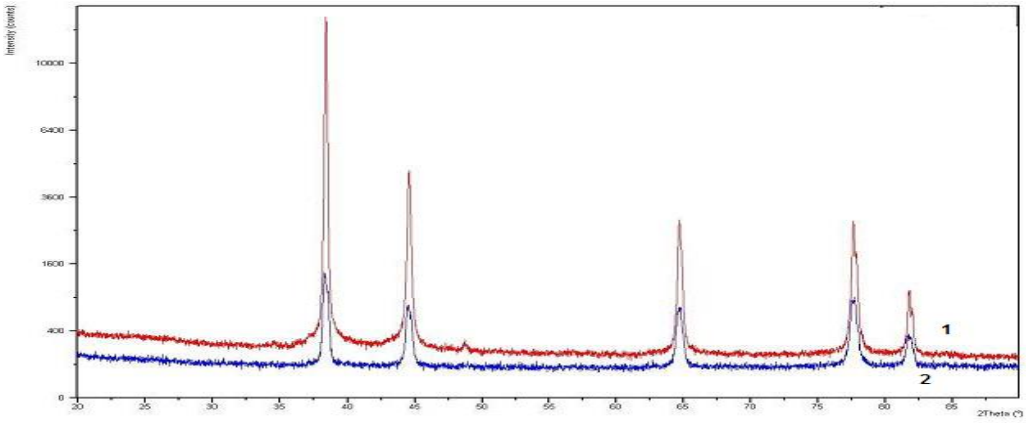


Fig. 9. XRD patterns of final product of pyrolysis of Ag(ibup) (1) and Ag(napx) (2)
Source: Author's

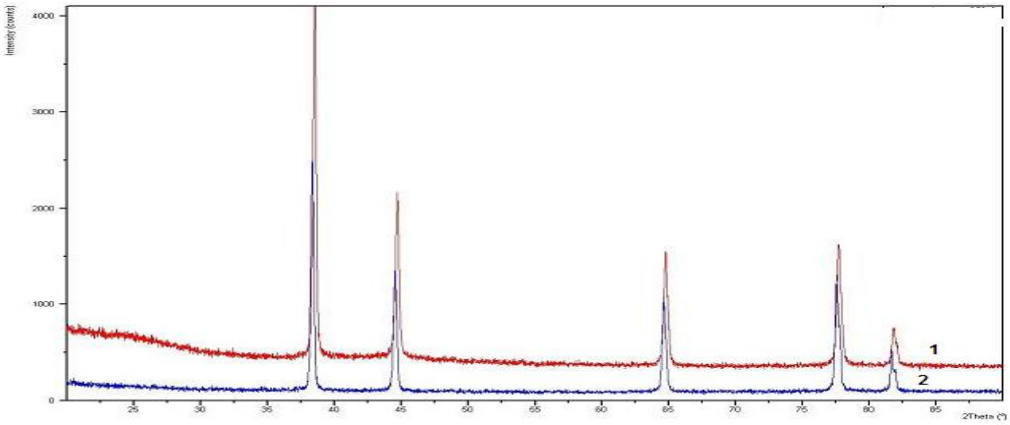


Fig. 10. XRD patterns of final product of pyrolysis of Ag(mef) (1) and Ag(ket) (2)
Source: Author's

Conclusion

The silver complexes with ibuprofen, naproxen, mefenamic acid and ketoprofen with formulae: Ag(ibup), Ag(napx), Ag(mef), Ag(ket) (Scheme 1) were synthesized and characterized.

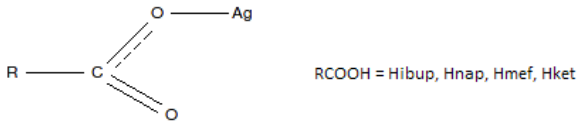


Fig. 11. Formula of complexes proposed according to elemental, IR and TG/DTG data
Source: Author's

IR vibrational spectra confirmed coordination bond formation between NSAID carboxylate groups, and silver ions and indicated that ibuprofenato, naproxenato, mefenamato and ketoprofenato anions act as monodentate ligands (on the contrary to Ag(I) complex with ibuprofen presented by Pereira E Silva [36]). The thermal investigations demonstrated that all synthesized complexes are highly thermal- proof, very closely to free ligands. Additionally they were stable over time.

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ENERGY EFFICIENCY IMPROVEMENT IN SMEs – ANALYSIS OF A PILOT PROGRAMME OF ENERGY EFFICIENCY MANAGEMENT IN POLAND

Abstract
This article includes an overview of methods of energy efficiency improvement in small and medium-sized enterprises (SMEs) applied in Poland. It describes the experience of the implementation of energy efficiency programme in Poland, introduced in 2013 by Polish Agency for Enterprise Development's. Evaluation of the programme shows that energy savings were over 6-times higher than expected by the programme's author before its implementation and amounted to 53 TJ. Financial savings were almost 5-times higher than expected and amounted to PLN 7.3m. Guidelines for decision makers which would be responsible for the development of similar programmes in the future are presented.

Key words:
energy efficiency, energy efficiency measures, energy efficiency programme for SMEs

Introduction

Power engineering is a strategic sector for the European Union [1]. Being the foundation for the functioning of the economy, it enforces the conduct of a responsible and rational policy that can provide energy security. The European Union is the second largest economy in the world and it is responsible for the annual consumption of 1.1 Gtoe of final energy, which constitutes approx. 20% of the global energy generation [1]. Most of this energy comes from import - in 2014 the European Union imported 53.5% of its energy. The dependence is different for each fuel and is the highest for petroleum-derived products – 87.4% of fuels is imported, followed by natural gas (67.4%), whereas the lowest dependence applies for solid fuels, primarily hard coal - dependence on external suppliers is 45.6% [2].

Therefore, due to the high dependence on external suppliers, the issues on efficient use of available resources including energy resource, become extremely important to the EU. Energy efficiency, in addition to reducing the greenhouse gases emission and energy generation from renewable resources, is one of the three pillars of the EU energy policy. "Europe 2020" strategy adopted in 2010 assumes reduction of the final energy consumption by 20% by 2020 [3]. Efforts are made throughout Europe aiming at increasing the energy efficiency, as well as the new responsibilities are adopted, with the perspective of execution by the year of 2030. Due to the specific role of small and medium size enterprises (SMEs) in the construction of economic development in the EU, as well as high energy consumption in this sector, dedicated programs are executed in this group. These actions aim at reducing energy consumption while maintaining at least a constant level of generation.

The issues of energy efficiency are also very important in Poland, and they result from economic and geographic conditions. Annual consumption of the final energy in Poland amounted to 60 Mtoe in 2014, while the annual average increase in demand for energy in the period of 2004-2014 amounted to 0.6% [4]. Along with the increase in demand for energy, the dependence from external supplies of energy resources was growing - while in 2004 Poland imported 14.5% of energy carriers, in the culminating year of 2011 it was already 33.4%. The increase in energy was mainly due to the increasing demand for petroleum, natural gas and their derivatives. In 2014, Poland purchased 72.0% of the annual consumption of natural gas from external partners and 93.1% of petroleum [2]. At the same time, the structure of resources supplies is unfavourable, with the majority of import from one direction - 82% of imported natural gas comes from the East, 13% from the West, and 5% from the South. One of the methods of reducing the demand for energy resources is improving the energy effectiveness. Industry, as a sector that held the third place in energy consumption (24% after housing and transport), is a significant field for taking actions in terms of energy efficiency.

Therefore, the activities of Poland in the field of energy efficiency do not solely stem from acceptance of the EU policy, but, above all, an internal need to build independence in terms of energy resources supplies from foreign partners. The adopted documents specifying the directions of energy policy establish energy efficiency as one of the primary areas of state intervention. The role of industry and entrepreneurs (the SME sector in particular, which dominates in the quantitative structure of enterprises) in the execution of tasks in this area seems to be natural, at the same time, however, the efforts of entities executing the programs for energy efficiency focus on other group of entities. The energy efficiency programs financed by public funds are dedicated to mainly local governments, managers of collective residential buildings and natural persons. Simultaneously, a great potential lies in the modernization of enterprises, which, however is not fully utilized. It is estimated that energy savings potential in European SMEs varies from 10% to 25% in industrial enterprises [5], [6]. At the same time there is an opinion that 40% of this potential might be utilized by implementation of non-investment measures [7]. There are also available other cost-effective energy efficiency measures, but due to several barriers they remain unimplemented. Experts divide these barriers into two types: financial and non-financial ones. Financial barriers include too high investments costs, low capital availability, and low profitability [8]. Non-financial barriers consist of limited in-house skills which would allow to identify and implement energy savings measures, as well as lack of time and difficulties in finding an external professional entity [9], [10], [11]. A well-prepared, SME-dedicated system program could be an impulse for major changes in the field of energy management in enterprises and a significant increase in the improvement of energy efficiency throughout the economy.

The aim of this work is to asses already finished programme, led by the Polish Agency for Enterprise Development (PAED) from 2013 to 2014, and to indicate which aspect of the programme were successful and which were not, so that these result might me used by entities responsible for a development of similar programmes in the future.

Methodology

The analysis was conducted based on two data sources. The first is the Polish Agency for Enterprise Development's (PAED) programme execution report [12], published by PAED. The second source of data are the Author's own analyses, performed based on the data collected during the execution of the program. Specifically, the data from 37 audit reports were included, being in the possession of the Author. 21 out of 37 reports are of Author's authorship. Out of 21 companies that the Author cooperated with, 12 companies decided to implement at least one of the recommendations resulting from audits and the data from these audits served also as the source material.

Energy efficiency improvement in SMEs programme in Poland

Background

The first major energy efficiency programme addressed to Polish enterprises was the project entitled "Testing and Implementing the pilot service in the field of energy efficiency management of enterprises", executed by the Polish Agency for Enterprise Development in the period of September 2013 - October 2014, and then continued until September 2015 by ten accredited entities throughout the country. The project consisted in testing the pilot service, in line with the "Required standard of performance in the field of energy efficiency management of enterprises" (hereinafter referred to as "Standard"). Services were executed in 484 enterprises. The main objective of the project was to verify whether the elaborated standard for the provision of energy audit services for SMEs was correctly identified, and, whether it is possible to achieve the assumed results. The aim of the project, from the point of view of an entrepreneur utilizing the service, was the development of enterprise through the improvement of energy use efficiency - e.g. by optimizing energy consumption, limiting its costs or improving the energy management system in the enterprise. The expected results were also to improve the competitiveness, profitability and potential of the enterprise. The obtained support of the advisory and training character was to help the enterprises in the process of transition from the micro scale to the level of small enterprises and form the level of small enterprises to the medium ones. After completion of the project, the tested service was to be offered by institutions cooperating with PAED on the principles that were to be developed during the project.

Service provision method

All services within the project were executed based on the Standard. The Standard incorporated the definition of energy efficiency, extending the previously used meaning of this term, coming from the Act of April 15, 2011 on Energy Efficiency. This definition added aspects of reducing the energy costs and utilizing the energy from renewable sources, to the technical measures aimed at reducing energy consumption. The measure aimed at improving the energy effectiveness within the meaning of the Standard can be, for example: thermal efficiency improvement of buildings, change of utilized sources and/or energy carriers, elimination of losses in transmission and use of thermal and power energy, the use of waste energy, possibility of selling the surplus of generated energy, monitoring energy consumption, possibility of changing the energy supplier and using special tariffs, reorganization of generation process, optimization of work organization, creation and operation of energy maintenance system, the use of energy from renewable sources and others [13], [14]. The applied approach should be regarded as beneficial from the point of view of the stakeholders of the Programme. It provided a wider range of options for actions for auditors, as it allowed them to include issues on optimization of energy costs (such as changing the energy supplier, changing the ordered capacity, eliminating the costs related to the overrunning of reactive power consumption). Enterprises, on the other hand, received a proposal of actions that are easy to implement, devoid of investment costs and bringing in the short-term cost reduction.

In the Polish legislation, there are no formal requirements specified for the profession of energy auditor. The standard of the service had to determine the requirements for persons who were supposed to conduct the audits. The auditors were presented with the following requirements:

- higher technical or economic education or
- secondary technical or economic education and 3 years of experience in the execution of advisory services regarding energy efficiency of enterprises and
- experience in the execution of at least 5 advisory services regarding energy effectiveness of enterprises gained during 5 years preceding the execution of the service.

Service structure

The service consisted of two stages: the first, compulsory, was an energy audit and usually covered an analysis of the energy management in the enterprise. The second stage, not mandatory, was the implementation of audit's recommendations with the assistance of the auditor. By assumption, the service was to be tailored to the specific nature of the business. The standard of the service assumed that the implementation of measures as part of the first stage was done using methodologies set forth in the relevant laws and regulations regarding energy audits and energy efficiency of enterprises. The audit report had to indicate the measures that would ensure the improvement of energy efficiency of the enterprise by at least 5% or provide the reason for why such savings are not possible to achieve. If the company decided to proceed to the second stage, it would have to perform the measures to ensure the generation of annual savings at the level of 5% minimum. The value of the service performed as part of the first stage amounted to PLN 4,500 (EUR 1,000), while the two stages in total amounted to PLN 10,700 (EUR 2,380). To proceed to the second stage, it was necessary to complete the first stage. Full costs of the service, as part of the programme, were settled as *de minimis* aid, therefore in real terms the enterprise did not incur any costs. Ultimately, the service cost for the entrepreneur was to amount to 30% of the service value, and the remaining 70% was to be covered as *de minimis* aid.

The service was available for micro and small enterprises whose annual energy consumption (including thermal energy, electricity, for transport and others) was no less than 500 GJ (138.9 MWh). In practice, in turned out that not too many micro and small enterprises meet this criterion, therefore the scope of the program was limited to the most energy-consuming industries.

The scope of audit

The energy efficiency audit is performed as part of the first stage of the service, under which the following took place:

- collection of data on energy consumption;
- assessment of the equipment technical condition;
- energy consumption analysis, identification of energy efficiency measures possible to implement and development of simplified economic analysis of these measures;
- indication of the level of energy savings that is possible to achieve;
- analysis of the behaviour of employees and clients;

- formulation of recommendations for introduction of changes in the energy efficiency management in the enterprise.

The audit report contained the characteristics of the enterprise and description of energy efficiency improvement, including, in particular: final and primary energy savings, costs of the measure implementation, financial savings and simply payback time (SPBT), the ecological effect in the form of avoided CO_2 emissions and, in justified cases, life cycle costs (LLC) and life cycle assessment (LCA).

The completion of the audit was to provide the enterprise with the audit report within 21 days of the completion of performance of all measurements and tests. Acceptance of the audit report by the enterprise ended the first stage. The conclusion of co-operation was possible at this stage, or, if the enterprise planned to implement any of the recommended measures, it was possible to proceed to the second stage.

The implementation of one or several recommendations from the previous stage took place as part of the second stage. The implementation could take place in one of the three levels:

- Level 1 - consulting in the implementation of changes in operation of buildings, systems or devices, e.g. by improving the selection of energy tariffs;
- Level 2 - consulting in the proper conduct of maintenance of technical and building infrastructure held in possession;
- Level 3 - consulting in the modernisation process of possessed technical and building infrastructure.

Only the performance of audit and consulting in the implementation of recommendations were financed as part of the programme. Any costs associated with the implementation of undertakings to improve energy efficiency were covered by the enterprise or through the use of external funding sources, but their acquisition was not part of the service.

Programme impact

The size of the programme

The programme was implemented in 484 enterprises throughout Poland. Entrepreneurs operating in the processing industry were the dominant group among the customers of the service (60%). The second largest group, but much less numerous compared to the first one, was comprised of customers conducting business in the retail trade and wholesale sector (10%). The remaining sections of the economy held a share of less than 6% [12].

For most entrepreneurs, the energy efficiency audit service was the first service of this type implemented in their company - 75% of companies never received the offer for a similar service, 55% of enterprises could not find the suitable service on the market, and for 50% of companies this kind of services were too expensive [12].

The results of the audits

Pursuant to the standard of the service, the measures aiming at improving energy efficiency could be, among others:

- thermal efficiency improvement;
- change of utilized sources and/or energy carriers;
- elimination of losses in transmission and in use of thermal energy and electricity;
- the use of waste energy;
- the possibility of selling the surplus of generated energy;
- energy consumption monitoring;
- the possibility of changing the supplier of energy and the use of special tariffs;
- reorganization of the production process;
- optimization of work organization;
- creation and operation of energy management system;
- the use of energy from renewable sources.

In the audits performed by all the entities implementing the project, the most recommended measures covered changes in the operation method of systems and devices and the replacement of devices with new ones, more energy-saving, or modernization and complement of the existing devices and systems. Also, the proposals to implement new procedures and solutions were frequent recommendations, that is - non-investment measures, requiring changes in behaviour and habits of employees. Recommendations on

maintenance, repair of systems, facilities or devices were also popular. All these measures appeared in more than half of the audit reports.

The proposed measures in varying degrees contributed to the physical improvement of energy efficiency in the enterprise. The largest factors were: a change in the operation of systems and devices, training of employees and implementation of procedures and organizational procedures to help reduce energy consumption. Non-investment measures had a large share in the generation of savings, thanks to which it was possible to achieve the assumed increase ceiling of energy efficiency. The structure of the share of individual measures to improve energy efficiency in enterprises are shown in Fig. 1.

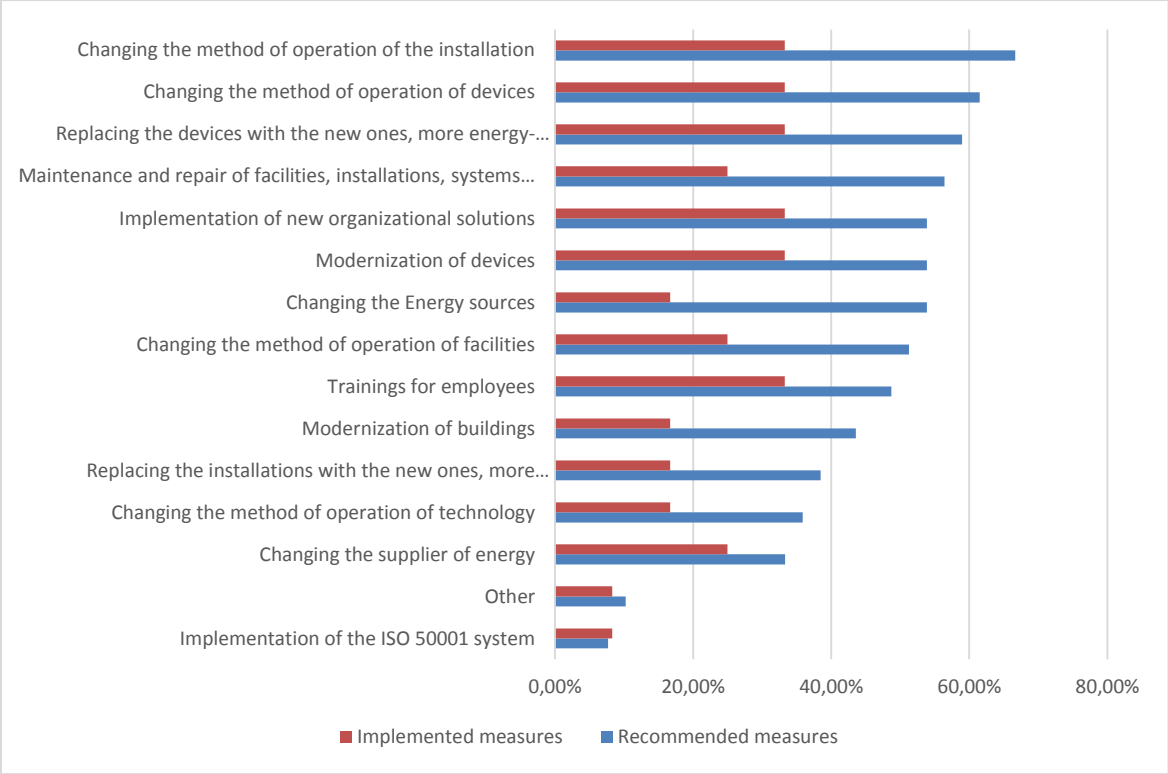

Fig. 1. Recommendations from audits and physical improvement of energy efficiency
Source: own study based on [12]

Implementations of recommendations

The vast majority of solutions proposed in audits were assessed by the enterprise as beneficial, and set for implementation. The most popular were simple non-investment measures, such as a change in the operation of equipment and employees training - 100% of entrepreneurs implemented or planned to implement these recommendations. On the other extreme, there were such measures as an implementation of ISO 50001 standard, a change in the source or supplier of energy - respectively 33.3%, 23.8% and 23.8% of entrepreneurs did not intend to exercise the proposals for implementation of these measures. Given the speed of implementation of recommendations, the measures that were implemented at the fastest rate, right after acquisition of the report, were non-investment measures: trainings for employees, organizational changes, changes in the energy supplier. More complicated measures requiring the investment were deferred, but planned for implementation. These measures comprised modernization of devices and buildings, replacement of equipment, changing energy suppliers, including one's own sources of energy. The structure of implementation in time of recommendations, suggested to enterprises in energy audit reports, is presented in Fig. 2.

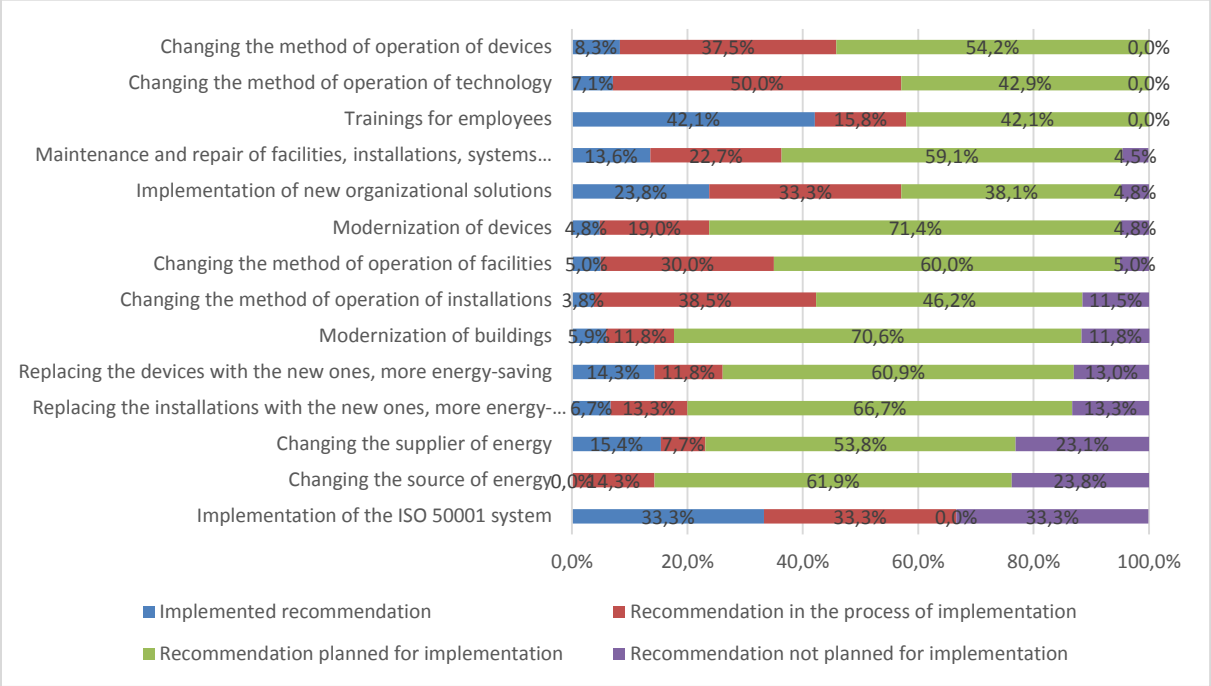

Fig. 2. The progress in implementing the measures recommended in audits
Source: [12]

The main reasons for the lack of implementation of recommendations were financial reasons - more than 40% of enterprises indicated this reason as an obstacle to taking up the measures suggested in the audit. A frequent reason was also the lack of time to implement the recommendations - entrepreneurs tend to focus on developing the core business, whereas the matters related to energy management are ignored and set aside, even if energy costs are a significant part of the budget. The lack of qualifications of employees was a relatively rare issue - it was indicated by only 4.5% of the surveyed companies [12]. The structure of problems in implementation of recommendations is presented in Fig. 3.

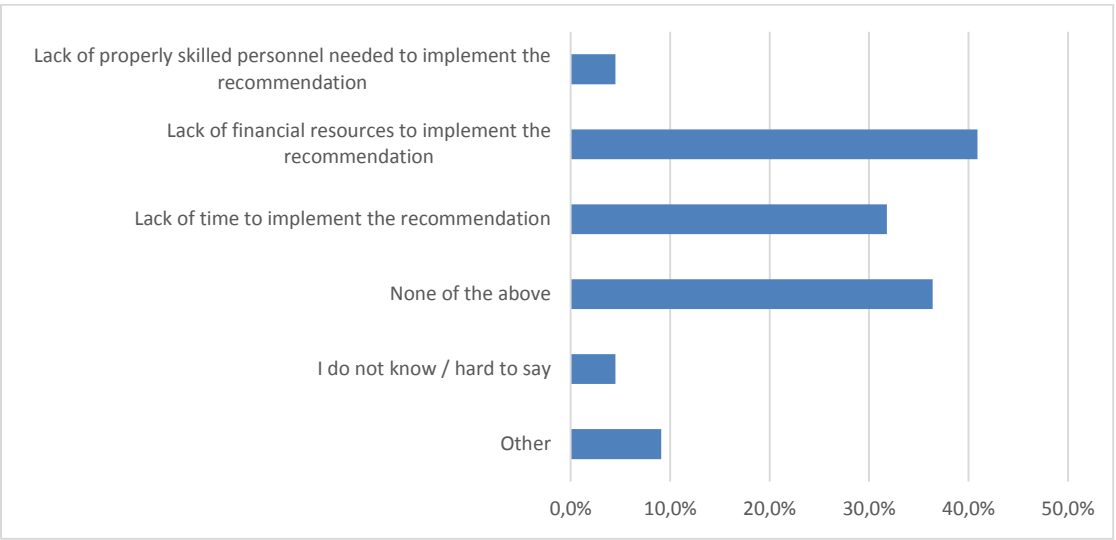

Fig. 3. Problems in the implementation of recommendations
Source: [12]

Program's effects in terms of energy
Pursuant to the provisions of the standard, each of the performed services was implemented in the enterprise consuming no less than 500 GJ of final energy annually. A minimum of 70% of enterprises taking part in the

project were to participate in the second stage of the service, meaning they were to implement recommendations improving the energy efficiency by at least 5%. Against 484 companies that joined the project, the minimum assumed energy savings amounted to 8.475 GJ.
During the implementation of the program it turned out that the assumed minimum is very easy to obtain, which resulted from two factors. The first one was the fact that the implementations executed by enterprises allow the increase of energy efficiency by more than 5% [12]. In 12 companies that cooperated with the author, and which implemented projects indicated in the audit, the average energy savings amounted to 9.25%. The second factor was an annual energy consumption by companies. Despite the fact that the level of 500 GJ was difficult to achieve for most micro and small companies, there are companies, however, which significantly exceed the indicated minimum. Fig. 4 shows the structure of the size of energy consumption by 39 enterprises, the audits of which were available to the author. The dominant group consisted of enterprises with annual energy consumption falling between 500-1,000 GJ. A slightly smaller group, but also numerous, comprised of companies consuming up to 2,000 GJ of energy. There were companies, however, with significantly higher consumption - two companies form the textile industry with consumption of more than 20,000 GJ, but there was also a company manufacturing building materials, with consumption of more than 60,000 GJ. The median of energy consumption among all companies amounted to 1,168 GJ, whereas the average (excluding the three companies with an extremely high energy consumption) – 1,706 GJ.

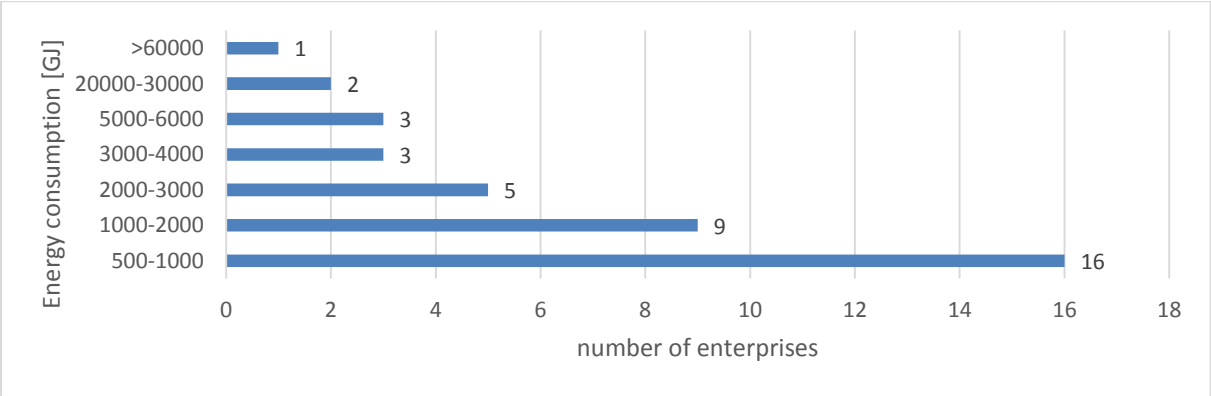

Fig. 4. Size structure of energy consumption by companies.
Source: Author's

Assuming the two means (9,25% - a statistical improvement of energy efficiency and 1,706 GJ - a statistical energy consumption in the company) as global data for the entire project, it can be assumed that the effect of the project implementation is the energy saving amounting to 53,489 GJ. This means that the assumed minimum is exceeded by more than 6 times.

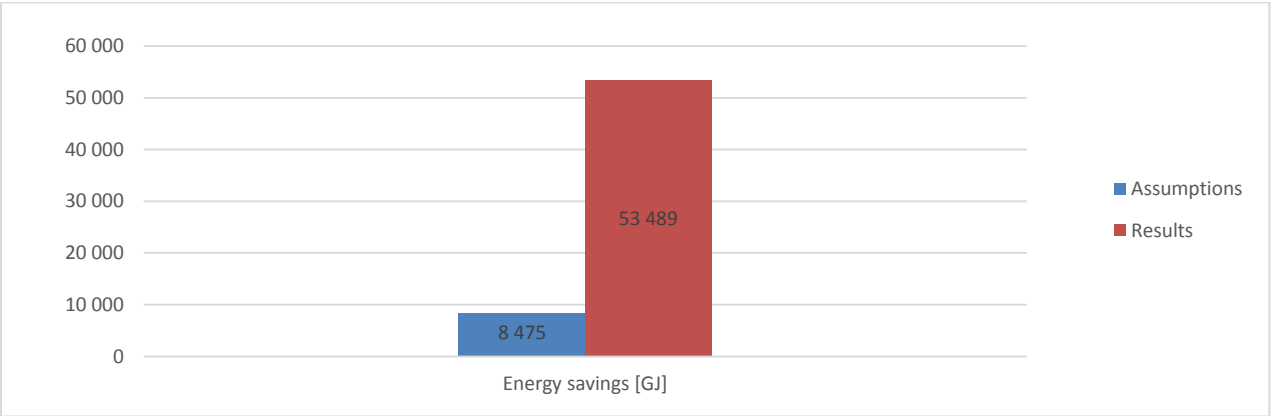

Fig. 5. Comparison of assumed and achieved energy savings
Source: Author's

Exceeding considerably the indicators assumed to achieve the indexes resulted, therefore, from cautious assumptions of the PAED programme. The main factor contributing to the significant increase in energy reduction was the fact of joining the project by a relative large number of enterprises, which were

characterized by higher energy consumption than the threshold ones, representing the eligibility criterion for the project (500 GJ). Moreover, the measures implemented by companies brought energy savings almost twice as great as the required minimum (9,25% against 5%).

Financial effect of the programme

The standard was based on the assumption that the final effect - improvement of energy efficiency of each beneficiary of the service by at least 5% - should cover the costs of energy audit, determined as a standard of PLN 4,500. Therefore, with the assumed structure of services - 70% ended with implementation, the assumed minimum financial effects of the project amounted to PLN 1,525 million in avoided energy costs in enterprises. The evaluation of the project indicated, however, that in 45% of enterprises the improvement of energy efficient amounted to more than 12% [12], in most of the companies, the baseline energy consumption was also higher. In 12 companies that cooperated with the author and which implemented the projects indicated in the audit, the average financial savings in relation to the energy saved amounted to 135.72 PLN/GJ. These profits resulted primarily from the reduced energy consumption, but also from the decrease in unit costs of energy, and the elimination of costs of accompanying measures. As a result, the estimated profits of all the enterprises participating in the second stage, after the implementation of recommendations, amounted to PLN 7.26 million, which is above the assumed minimum effect by 475%. The comparison of assumed and achieved financial savings is presented in Fig. 6.

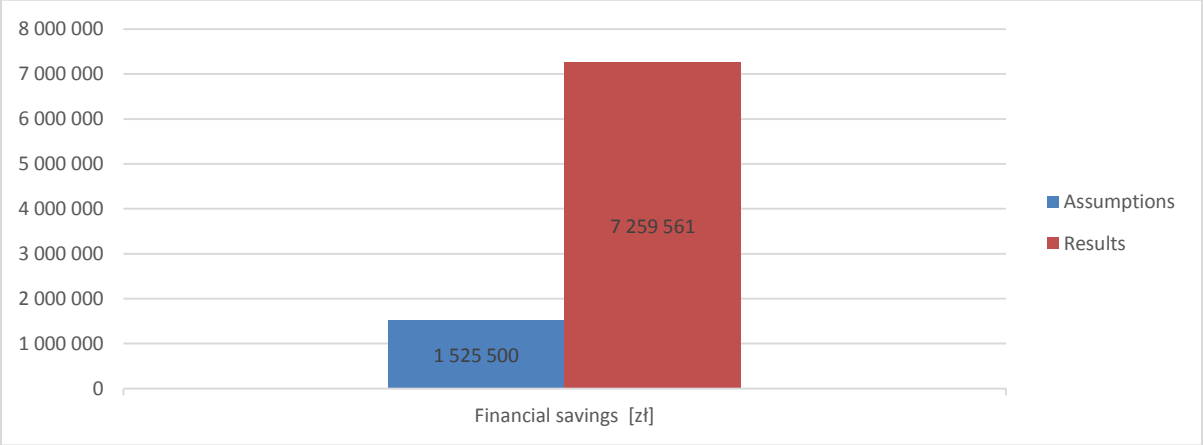

Fig. 6. Comparison of assumed and achieved financial savings
Source: Author's

Ecological effects

Assumptions of the project did not foresee targets for ecological effects. The standard, however, indicated the necessity of calculating the CO_2 for the recommended measures. Referring to the reduction of other pollutants did not fall within the standard. In certain calculations, however, it was justified to calculate ecological effect also in terms of dust emission, SO_2, NOx and CO. This resulted from the formal requirements of National Fund for Environmental Protection and Water Management in Poland when applying for funding of the measures implementation.

The adoption of a specific methodology of calculating the emission reduction was the author's decision. The author of this work and the three auditors, who shared their audits with the Author, used the following formula:

$$\Delta E_i = \Delta Q_p * e_i$$

Where:

$\Delta E_i - reduction\ of\ emission\ of\ compound\ i$

$\Delta Q_p -\ reduction\ of\ consumption\ of\ primary\ energy$

$e_i - emission\ indicator\ of\ compound\ i$

Emission indicators were adopted in line with the current tables published by the National Centre for Emissions Management in Poland.

In 12 companies that cooperated with the author and implemented the undertakings indicated in the audit, the average energy consumption reduction by 1 GJ was associated with the emission reduction of CO_2 by 0.1976 Mg. The estimated effect of the entire project is 10,572 Mg of avoided CO_2 emissions. Given the insufficient amount of data, it is not possible to determine the remaining ecological effects.

Comparison of Polish programme to energy efficiency public programs in selected countries

Energy efficiency improvement programs are implemented in many countries - they were described in, among others: [15], [16], [17], [18], [19], [20], [21]. The authors described the work methodologies utilized in different countries, dependent on local conditions, including the challenges in the field of regional entities' energy management, energy auditors experience, legal requirements or the needs of entrepreneurs. Organizational and financial issues of such programmes were also described. This part of the article presents the comparison of the programmes in Poland, Germany, Italy, Sweden and China.

Measures undertaken in different countries vary in the level of details and target groups. A German project „Sonderfonds Energieeffiezienz in KMU" was interesting from the point of view of Polish experiences, in which the performed energy audit authorized to apply for a preferential loan to implement projects aiming at improvement of energy efficiency. The combination of energy efficiency audits with the funding programme resulted in an increased efficiency of the programme in the form of implementations and it was one of the factors, for which the enterprises decided to exercise the audit. Similar experiences were shown by the project executed in Lombardy, Italy. A solution that was also interesting and worthy of adopting was to divide the audits into stages, from which the first one was a description of undertakings, and the second one was a detailed analysis of measures selected by entrepreneurs. Such an approach allows better engagement of entrepreneurs in the process of creation of action plans, which are included in the audit report, and it increases the likelihood of implementation of the recommendations. On the other hand, the Swedish experiences from the execution of the SEAP project - Swedish Energy Audit Programme, show which elements of the energy efficiency audit programmes in the SMEs are not working. The main issue was to ensure a correspondingly high quality level of audits and small possibilities of selecting a company providing audits - both in terms of competence and service costs. Thus, creating a similar programme, it is necessary to create a set of guidelines in line with which the audit should be performed, as well as there should be market conditions created that would make room for the free and natural development of energy services market.

Table 1. Comparison of energy efficiency improvement programmes in selected countries

Country	**Poland**	**Germany**	**Italy (Lombardy)**	**Sweden**	**China**
Name	Testing and implementation of a pilot service in the field of energy efficiency management in enterprises	Sonderfonds Energieeffiezienz in KMU	n/a (regional project)	SEAP – Swedish energy audit program	Top-1000
Years of implementation	2013-2014	2008-2010	n/a	2010-2014	2006-2010
Target group	micro and small enterprises	SME	SME	SME, large firms in several cases	1,008 largest energy-consuming enterprises (combined accounted for one-third of China's total energy use and almost half of industrial energy use in 2004)
Number of audits	484	4434	71	554 (by 2012)	1008
Audit cost share paid by company	0%	20%	50% (max. 3,000 EUR)	64% (2,700 out of 7,500 EUR in average)	100% After implementation of energy efficiency measure possibility to receive monetary reward of 1.0-1.5 USD for each GJ of saved energy

Source: Author's

Discussion on programme's results

The PAED programme was the first energy efficiency improvement programme in the SME sector in Poland executed on such a large scale. Since it was a pilot programme, it was oriented on testing and verifying the assumed requirements and procedures. The programme's aspects that received a positive verification are:

- the opportunity to include in the audit not only technical improvements, but also financial ones, only lowering the costs of energy, but not its consumption;
- the audit's performance standard referring to the existing standards and legal regulations;
- the report's standard presenting the audit's results in a manner understandable for an entrepreneur, who is not an expert in the field of energy efficiency;
- covering only part of the audit's costs by the enterprise;
- adjusting the scope of the audit to the specifics of a given company - an opportunity to skip these elements of the audit, which hold no significance to the company.

On the other hand, the elements of the programme that require modifications are:

- insufficient level of funding planned for the programme administrative support (30%) - real costs were higher due to increased work input connected with communication with entrepreneurs;
- underrated appraisal of the audit's first stage and overrated appraisal of the other;
- no connection with the programme supporting investments in energy efficiency;
- too high a barrier to entry the programme - the most of micro and small companies in Poland consume significantly less energy than 500 GJ/year.

Next steps

The next steps of the author assume the development of guidelines for entities willing to exercise similar programmes in the future.

Conclusion

Evaluation of the programme "Testing and Implementing the pilot service in the field of energy efficiency management of enterprises", executed by the Polish Agency for Enterprise Development in the period of September 2013 - October 2014 shows that the achieved impact significantly exceeded the initially assumed one, both in terms of energy and financial savings. Nevertheless, since the programme was focused not only on energy savings, but also on verification of the programme assumptions and the methodology, there can be indicated areas which require improvements. The most important ones are the connection between the auditing and the funding programme as well as the decrease of an entry barrier to make the programme more accessible. On the other hand, there are many aspects of the programme that were verified positively and should be replicated in other similar programmes: a wide range of possible improvements which would be proposed to an enterprise (not only technical ones) and a form of the audit report which is written in an easy language which is understandable by no-experts.

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IDENTIFICATION AND QUANTIFICATION OF THE FISCAL EFFECTS OF ELECTRICITY GENERATION IN POLAND

Abstract
The economic costs of electricity generation in Poland differ significantly from its accounting costs. Overt and covert forms of public support and taxation obscure the picture of the relationship between the public sector and the energy industry, and give rise to speculations whether one generation technology is privileged over another, i.e. used more often than other technologies with lower economic costs. The analysis presented in this article shows that there are significant differences in terms of impact of individual electricity generation technologies on public finances in Poland.

Key words:
electricity, cost-benefit analysis, public finances, energy economics, energy subsidies

Introduction

The scope and impact of government interventions on energy markets have been the topic of both public debate and scientific studies for years, e.g. by the European Commission [1], Organisation for Economic Cooperation and Development [2], International Monetary Fund [3]. To date, however, different energy generation technologies have not been compared explicitly from the point of view of their influence on the performance of public finances. The issue is particularly challenging in Poland, where one of the main targets of the planned National Energy Policy by 2050 [4] is to "rationalise the costs of primary energy", with limited reflection on the existing differences between the actual economic and accounting costs. These differences may be caused by external costs, but also by the overt and covert forms of public support and taxation for different energy generation technologies. This paper aims at addressing this question by identifying and quantifying the net streams between the public finances and different energy generation technologies in Poland.

We define positive fiscal effects as financial and non-financial benefits achieved by the public sector, whereas the negative fiscal effects as the financial and non-financial costs incurred by the public sector. The primary source of positive fiscal effects are taxes [5]. Their general typology can be considered by the subject of taxation, as well as by their intended use and the relation of the subject of taxation to the source of taxation. Apart from traditional forms, such as income taxes, electricity companies in the EU pay also special taxes, for instance: tax on installed electric power, payable in France for local and regional authorities. In certain countries, there are exotic forms of taxation, for example in Hungary – a charge for the reduction of energy cost for former and current employees of power industry, or a charge for the restructuring of the coal industry. On the other hand, the negative fiscal effects (transfers of values from the public sector to the private sector – energy industry) may concern: direct capital transfers, tax revenue foregone, other government revenue foregone, transfer of risk to the public sector, or induced transfers [6].

As far as the implications of the fiscal effects are concerned, they may be twofold. Energy subsidies may have distortionary impact on the energy market, leading to changes in overall energy consumption [7], carbon emissions [8], income redistribution [9]. On the contrary, several sources of fiscal receipts directly related with energy generation can also have a strong positive stimulus for effective implementation of public environmental policies or local development initiatives (e.g. property taxes) [10].

The article focuses on estimating the positive and negative fiscal effects of electricity generation in Poland, in relation with the following energy carriers: hard coal, lignite, natural gas, biomass, biogas, wind energy, solar energy. We use several types of data sources, such as statistics and reports published by EU and Polish public authorities at different levels of governance, as well as a number of case studies describing several types energy generation installations and the taxes related with their costs and revenues. This data analysis approach

aims to develop a conceptual framework for providing clear comparison between different energy generation technologies in terms of their influence on the public finances in Poland. The fiscal effects analysed are expressed in monetary units per MWh of electricity, generated using different technologies (hard coal, lignite, natural gas, biomass, biogas, wind energy, solar energy), which allows for direct reasoning and drawing conclusions that may be useful for energy mix planning by decision makers of public energy policy.

Positive fiscal effects

The positive fiscal effects connected with electricity generation in Poland, understood as public sector receipts, include:

- value added tax (VAT),
- income tax,
- land tax,
- property tax,
- environmental fees, including fees for CO_2 emissions,
- excise duty [6].

VAT tax

We estimate the budgetary receipts from VAT, associated with an added value obtained from various energy technologies, based on the 2012 *Balance sheet financial results of business entities* [11]. The basic rate of tax was adopted in line with the Polish standard VAT tax rate (23%). Due to the lack of available sources on the added value obtained at the generation of one MWh of electricity with the use of various technologies, in order to estimate the value added tax, we assume that the tax value can be calculated upon the base of the sum of the electricity price (per one MWh) and the price of green certificates (per one MWh, if applicable – the green certificates are granted by relevant public authority for production of electrical energy from renewable energy sources and high-performance co-generation using natural gas) [11].

Table 1. Estimated value of VAT according to energy carriers [PLN/MWh]

Description	hard coal	lignite	natural gas	biomass	biogas	wind energy	solar energy
Electricity price on competitive market (price on Polish Power Exchange) [PLN/ MWh]	201.36	201.36	201.36	201.36	201.36	201.36	201.36
Price of property rights or green certificates[1] [PLN/MWh]	0.00	0.00	123.43	253.31	389.38	253.31	253.31
Total price [PLN/MWh]	201.36	201.36	324.79	454.67	590.74	454.67	454.67
VAT [PLN/MWh]	46.31	46.31	74.70	104.57	135.87	104.57	104.57

Source: Author's calculations based on [6]

The obtained results of calculations indicate that the amount of VAT is very highly dependent on the level of prices for the green certificates. The accounting added value, from which VAT is charged, is therefore considerably greater in the case of non-conventional technologies.

[1] Green certificates are tradable commodities proving that certain electricity is generated using renewable energy sources. One certificate represents generation of one MWh of electricity and it is granted to the energy producer by the relevant public authority (Energy Regulatory Office).

Income tax

The energy industry pays 2.8 billion PLN annually to the state budget by way of income tax and corporate income tax (CIT) [12]. To estimate the share of receipts from CIT, we estimate the profitability of electricity generation from various technologies, which is shown in table 2[2].

Table 2. Estimated value of CIT according to energy carriers [PLN/MWh]

Description	hard coal	lignite	natural gas	biomass	biogas	wind energy	solar energy
CAPEX [EUR/MWh] [1]	39	39	51	96	30	70	85
OPEX [EUR/MWh] [1]	7	7	6	26	10	11	22
Total costs [EUR/MWh]	46	46	57	122	40	81	107
Electricity price [EUR/MWh] [1]	108	108	108	108	108	108	108
Price of property rights [EUR/MWh] [13]	0	0	30	62	95	62	62
Total selling price [EUR/MWh]	108	108	138	170	203	170	170
Profitability [EUR/MWh]	62	62	81	48	163	89	63
Profitability [PLN/MWh][3]	254	254	332	196	668	364	257
CIT prior to correction [PLN/MWh]	48	48	63	37	127	69	49
Amount of energy generated annually in Poland [GWh] [14]	87,326	52,529	5,821	7,459	142	3,205	0
Estimated CIT prior to correction (19%) [mln PLN]	4,213.8	2,534.7	367.6	277.7	18.0	221.6	0.0
Estimated CIT after correction [mln PLN][4]	1545.7	929.8	134.8	101.8	6.6	81.3	0.0
Estimated CIT after correction [PLN/MWh]	**17.70**	**17.70**	**23.20**	**13.70**	**46.60**	**25.40**	**0.00**

Source: Author's calculations based on [1], [12], [13], [14]

The resulting estimates regarding the income tax indicate that the state budget can expect the largest unit receipts from CIT [in PLN/MWh] from the producers of electricity from biogas and wind (46.6 PLN/MWh and 25.4 PLN/MWh respectively). Due to the very low generation of electricity from solar energy in the National Power System, it was impossible to estimate the value of income tax paid by photovoltaic power plants.

Property tax

Property tax rates are determined by means of resolution of local councils. The law on local taxes and charges regulates only the maximum rates – e.g. 22.82 PLN per 1 m^2 of functional area and 2% of the value of buildings [15]. To assess fiscal receipts from the property tax on various types of power plants, Tables 3, 4 and 5 propose the calculation of the estimate based on three case studies: a lignite-fired power plant in Bełchatów, a biogas power plant in the province of Świętokrzyskie and a wind power plant in the province of Łódź.

[2] There is no data on the profitability of individual energy technologies at the state level. The data accepted from the EU level were corrected, matching the profitability structure at the EU level to Polish conditions.

[3] Adopted exchange rate: 4.1 PLN/EUR. Exchange rate applied to all energy generation technologies analysed.

[4] The adopted correction assumes that the profitability structure of the generation technology in Poland corresponds to the profitability structure in the EU, but the total profitability is proportionately smaller. The total amount of CIT was calculated on the basis of [12].

Table 3. Estimation of the amount of the property tax for a conventional electricity generation system (hard coal, lignite, natural gas)

Item	Value
Tax value [PLN/capita] [16]	33,100
Number of inhabitants [17]	5,165
Total value of the property tax [PLN]	170,961,500
Total electricity generation in power plant in Bełchatów [MWh] [18]	28,000,000
Value of the property tax [PLN/MWh]	6.11

Source: Author's calculations based on [16-18]

Table 4. Estimation of the amount of the property tax for biomass and biogas installations

Item	Value
Amount of the property tax [PLN/MW] [19]	100,000
Estimated operation time annually [h]	8,400
Value of the property tax [PLN/MWh]	11.90

Source: Author's calculations based on [19]

Table 5. Estimation of the amount of the property tax for the wind power industry

Item	Value
Value of the property tax [PLN] [20]	2,386,000
Estimated generation of electricity [MWh] [20]	151,200
Property tax value [PLN/MWh]	15.78

Source: Author's calculations based on [20]

Table 6 presents the summary of estimated property tax values, broken down into generation technology. As expected, the largest single receipts from the property tax relate to the wind power industry (15.78 PLN/MWh). The property area in the case of wind power plants includes not only the land occupied by the turbine tower, but also the area swept by the rotor of the turbine, tower surface and access roads. The lowest property taxes (zero) apply to the solar power plants, which are not considered real properties [21].

Table 6. Estimated value of the property tax according to energy carriers [PLN/MWh]

Item	hard coal	lignite	natural gas	biomass	biogas	wind energy	solar energy
Estimated value of property tax [PLN/MWh]	6.11	6.11	6.11	11.91	11.91	15.78	0.00

Source: Author's Author's calculations

Environmental fees and compensatory payments

Annual receipts of the National Fund for Environmental Protection and Water Management (NFOŚiGW) and 16 Regional Funds for Environmental Protection and Water Management (WFOŚiGWs) from fees and penalties for damaging the environment, as well as the remaining fees paid by the companies amount to approx. 1.84 billion PLN. As we show in Table 7, the largest amount comes from compensatory payments and penalties, resulting directly from the Energy Law.

Table 7. Annual receipt of NFOŚiGW related to charges incurred by energy companies and other [PLN thousand]

Description	Amount [PLN thousand]
Fees and penalties for using the environment	384,229
Usage fees and license fees	192,913
Product fees	3,630
Registration fees for the issue of integrated permits	1,195
Fees referred to in art. 142 of the Water Law Act	12,018
Fees for granting of emission allowances	217
Fees for substances depleting the ozone layer	376
Compensatory payments and fees resulting from the Energy Law Act	470,447
Penalties resulting from the Waste Act	2,801
TOTAL	**1,067,826**

Source: own study based on [22]

On the other hand, as shown in Table 8, the largest receipts from fees for the use of the environment and penalties at the provincial level are recorded by WFOŚiGWs in Łódź and in Katowice – 142 million and 125 million PLN respectively. In 2015, more than 33% of the total generation capacity of the Polish energy sector was installed in these provinces [23]. Receipts to WFOŚiGWs in these provinces constitute similar share (35%) of the total receipts of all WFOŚiGWs in Poland.

Table 8. Annual receipts of WFOŚiGWs from fees for the use of the environment and penalties [PLN thousand]

Province	Amount [PLN thousand]
Dolnośląskie	57,459
Kujawsko-pomorskie	40,561
Lubelskie	25,595
Lubuskie	13,549
Łódzkie	142,431
Małopolskie	44,176
Mazowieckie	90,215
Opolskie	22,984
Podkarpackie	20,021
Podlaskie	9,574
Pomorskie	36,591
Śląskie	125,781
Świętokrzyskie	25,116
Warmińsko-mazurskie	15,137
Wielkopolskie	62,012
Zachodniopomorskie	41,234
TOTAL	772,436

Source: own study based on [22]

Table 9 shows the estimate of the environmental charges connected with the electricity generation from hard coal in Poland. Per MWh, the greatest costs incurred by energy companies refer to charges for sulfur from combustion gas desulfurization (more than 4 PLN/MWh).

Table 9. Environmental fees related to the generation of electricity from coal

Specification	**Coal of average parameters in international trade classifications (class 25/12/08)**	**Coal of average parameters in the Polish professional power engineering classification (class 25/22/08)**	**Coal of average parameters in the Polish professional power engineering classification (class 18/25/12)**
Fees for storage of waste and for dust [PLN/tonne]	4.6	8.4	9.5
Fees for sulfur from flue gas desulfurization [PLN/tonne]	8.8	8.9	13.5
Fees for emission of NO_x, CO and CO_2 [PLN/tonne]	2.6	2.3	1.9
Sum of charges [PLN/tonne]	16.0	19.54	24.89
Fees for storage of waste and for dust [PLN/MWh]	1.8	3.8	5.3
Fees for sulfur from flue gas desulfurization [PLN/MWh]	3.5	4.1	7.5
Fees for emission of NO_x, CO and CO_2 – emission permits [PLN/MWh]	1.0	1.0	1.1
Sum of charges [PLN/MWh]	6.4	8.9	13.8

Source: own calculations based on [24]

To estimate the environmental charges from the remaining energy technologies considered, we assume that the fees are proportional to the equivalent emission factor characterizing the utilized energy carrier. The results of calculations are presented in Table 10.

Table 10. Estimation of environmental charges related to the generation of energy from various energy technologies

Specification	**hard coal**	**lignite**	**natural gas**	**biomass**
Equivalent emission factor [t CO_2-eq /MWh] [25]	0.385	0.375	0.237	0.002
Environmental fees [PLN/MWh]	8.9 [24]	8.67	5.48	0.05

Source: The author's own study based on [25]

The conducted calculations show that the largest unit environmental fees relate to hard coal power plant (8.9 PLN/MWh). It is worth noting that the amount of these fees is several times less than the amount of VAT and CIT tax. The largest part of environmental fees relates to fees for sulfur from flue gases desulfurization. Estimated environmental fees are the smallest in the case of wind and solar power plants (0 PLN/MWh), which are characterized by relatively low impact on the environment.

Excise duty

Pursuant to art. 9 of the Act of December 6, 2008 on excise duty [26] the following are subject to excise duty:
1) intra-community acquisition of solar energy by the final purchaser;
2) the sales of electricity to the final purchaser within the country, including by the entity without the license for generation, transmission, distribution or trade of electricity within the meaning of the Act of April 10, 1997 - the Energy Law, who generated this energy;
3) electricity consumption by the entity holding the license referred to in item 2;
4) electricity consumption by the entity without the license referred to in item 2, who generated this energy;
5) import of electricity by the final purchaser;
6) electricity consumption by the final purchaser, if the excise duty was not paid in the due amount and it is impossible to identify the entity, who executed the sale of electricity to the final purchaser. Pursuant to

appendix no. 1 to the aforementioned Act, on the other hand, the excise duty must also be settled from hard coal, brown coal and natural gas.

Table 11. The estimated value of the excise duty according to energy carriers

Description	**hard coal**	**lignite**	**natural gas**	**biomass**	**biogas**	**wind energy**	**solar energy**
Rate of excise duty according to energy carrier [PLN/GJ in fuel] [27]	1.3	1.3	1.3	0.0	0.0	0.0	0.0
Rate of excise duty from energy carrier [PLN/GJ in fuel]	4608.0	4608.0	4608.0	0.0	0.0	0.0	0.0
Energy conversion efficiency [%] [28]	32.3	39.6	26.8	31.9	29.9	–	–
Rate of excise duty from energy carrier [PLN/MWh electricity]	14.3	11.6	17.2	0.0	0.0	–	–
Rate of excise duty from electricity [PLN/MWh] [27]	20.0	20.0	20.0	20.0	20.0	20.0	20.0
The rate of excise duty in total [PLN/MWh]	34.3	31.6	37.2	20.0	20.0	20.0	20.0

Source: own study based on [27] and [28]

The calculations performed show that single budgetary receipts from excise duty are the greatest in the case of power plants fired by natural gas (37.2 PLN/MWh), which derives from the highest rates of excise duty from energy carrier, as well as the lowest conversion efficiency of primary energy to final energy, from among the considered technologies.

Negative fiscal effects

In 2012 the hard coal mining sector received subsidies worth 5,591 million PLN [29], including:

- PLN 861 million – from the state budget and support programs for the hard coal sector;
- PLN 8 million – from the Infrastructure and Environment Operational Program, the Innovative Economy Operational Program and the LIFE+ program;
- PLN 300 million – form the Silesia Province Regional Operational Program
- PLN 4,421 million – for miners' pensions (data for 2012).

Therefore, the subsides per unit of electricity generated from hard coal amount to 64 PLN/MWh. Calculations by CASE-Doradcy show that the value of subsidies for the coal mining in the years of 2010-2012 was 60% greater than the value of support for the renewable energy sector. According to the OECD, on the other hand, the Polish coal sector receives PLN 2,535 million per year from the public support (data as of 2011) [2], including:

- support for manufacturers – compensations for stranded costs (PLN 2,128 million),
- support for consumers – coal benefits in the hard coal mining sector (PLN 162 million),
- support for services – assistance for closing the mines (PLN 214 million), recultivation of the areas transformed as a result of mining activities (PLN 9 million), pre-retirement benefits for dismissed miners (PLN 22 million).

Therefore, the public support per unit of electricity generated from hard coal according to the OECD amounts to 29 PLN/MWh. Yet another results are provided by the International Monetary Fund [3], according to which the public support for the coal sector is annually approx. EUR 6.82 billion and EUR 0.7 billion for the gas sector, which is, respectively, approx..: 327 PLN/MWh and 56 PLN/MWh[5]. The cited analyses are not comparable, though. Elaborations of the IMF include external costs, whereas analyses of the OECD and CASE-Doradcy do

[5] Adopted rate: 4,1 PLN/EUR.

not. The estimates similar to analyses of the OECD can be found in the report by ECOFYS, commissioned by the European Commission [1], the results of which are presented in Table 12. Due to the fact that the ECOFYS' data have been verified by the European Commission and they fall within the confidence limit, specified by elaborations of CASE-Doradcy and of the OECD, the calculation from this particular source are considered for further deliberations.

Table 12. Structure of subsidies to energy technologies according to energy carriers in Poland 2012

Specification of fiscal effects	**hard coal**	**lignite**	**natural gas**	**biomass**	**biogas**	**wind energy**	**solar energy**
Subsidies [EUR million]	730	4.5	30	50	0[6]	20	30
Subsidies [PLN/MWh][7]	34.2	0.4	21.1	27.5	0.0	25.6	0.0

Source: own study based on [1]

Table 13 presents the comparison of the main fiscal effects related to electricity generation in Poland according to energy carrier. The biggest net positive financial receipts per MWh are recorded by the public sector by generating electricity from biogas, whereas the lowest gains come from generating electricity from hard coal. However, our analysis does not cover external effects, which represent a significant economic cost, especially for certain technologies like hard coal and lignite.

Table 13. Comparison of the main fiscal effects related to electricity generation in Poland according to energy carriers

Specification of estimated fiscal effects [PLN/MWh]		**hard coal**	**lignite**	**natural gas**	**biomass**	**biogas**	**wind energy**	**solar energy**
FISCAL RECEIPTS	VAT	46.31	46.31	74.70	104.57	135.87	104.57	104.57
	CIT	17.70	17.70	23.20	13.70	46.60	25.40	0.00
	Property tax	6.11	6.11	6.11	11.91	11.91	15.78	0.00
	Environmental fees	8.9	8.67	5.48	0.05	0.00	0.00	0.00
	IN TOTAL	**79.02**	**78.79**	**109.49**	**130.23**	**194.38**	**145.75**	**104.57**
FISCAL EXPENDITURES	Subsidies	34.2	0.4	21.1	27.5	0.0	25.6	0.0
	IN TOTAL	**34.2**	**0.4**	**21.1**	**27.5**	**0.0**	**25.6**	**0.0**
NET RESULT		**44.82**	**78.39**	**88.39**	**102.73**	**194.38**	**120.15**	**104.57**

Source: Author's

Conclusions

The estimated fiscal receipts from the state budget and non-budgetary funds obtained from energy companies exceed the amount of granted subsidies, regardless of the type of electricity generation technology. The largest component of individual fiscal effects [PLN/MWh] for all the considered technologies is VAT. There is significant difference as to the scale of impact of particular technologies on public finances.

[6] There are no complex data sources that could verify the ECOFYS estimates regarding the subsidies for the biogas plant, but the null value presented in the report raises doubts.

[7] Adopted rate: 4,1 PLN/EUR.

According to the presented results, the biggest net fiscal receipts concern electrical energy generated from biogas, biomass, sun and wind. The main underlying reason for this is the green certification scheme, which promotes the generation of energy from renewables in Poland. As the price of certificates is the basis for VAT calculations, they strongly contribute to the increase of tax revenues. The second most important source of fiscal receipts in all cases analysed is CIT. However, the results in this field are also very much dependent on the price of green certificates. Even though environmental fees resulting from generation of one MWh of electricity based on hard coal and lignite constitute a significant fiscal burden for this technology, they are still estimated to be much smaller than real property taxes paid by owners of wind turbine as well as biomass and biogas installations.

As far as the fiscal expenditures are concerned, the subsidies granted to different power plants seem to be the highest in the case of installations based on hard coal. Public support offered to biomass and wind energy power plants is also significant, but much lower, as also pointed in [30]. In all cases, the subsidies offered are smaller than the fiscal receipts per one MWh of energy generated. Therefore, we have showed that – at least in comparison to the fossil fuel-based installations – renewable energy plants are not privileged in terms of subsidies received, contrary to some popular beliefs in Poland [31].

Even though the presented analyses compile several disparate figures and data sources on various taxes and subsidies to be assessed on a PLN/MWh basis, future research should extend and cross-validate them with other sources of information. Furthermore, the determination of deadweight loss from the point of view of social costs, resulting from the non-optimal fuel structure in the Polish energy sector, is not possible without the quantification of external effects. It should be further investigated whether current levels of environmental fees allow for full internalization of those effects, safeguarding Poland's socioeconomic interests and sustainable development in the long run.

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NEW METHODS OF HOPPING (DRYHOPPING) AND THEIR IMPACT ON SENSORY PROPERTIES OF BEER

Abstract
Due to the significant changes on the beer market the flourishing development of small and craft breweries is clearly observed. Upgraded consumers' expectation led to many technological challenges in brewing process resulting in novel methods of manufacturing of many different beer types. As bitterness and aroma are two crucial quality features of beer and many scientific efforts have been done especially in the area of hop aroma. Despite the predominant impact of main beer flavor compound e.g. linalool, other substances also contribute to the hoppy beer aroma through additive or synergistic effects not only raw materials used but also hopping regimes contribute as well to final flavor release though several new methods of hopping, particularly dry hopping have been developed.

Key words
Hop, dry hopping, beer, bitterness, aroma, hopping

Hops as a raw material in brewing

Hops (*Humulus lupulus l.)* is a perennial, dioecious plant belonging to the *Cannabaceae* family. The brewing industry utilses only the female hops in the form of whole cone or their products (granulates or hop extracts) containing bitter resins, polyphenols and essential oils. They contribute to beer the bitter and aromatic substances [1]. Bitter substances (hop resins) consist 10-30% of the dry weight of hops (d.w.h). These substances are divided into soft resins (9-27.5% d.w.h.), which include alpha-acids and beta-acids and hard resins (1.5-2.5% d.w.h.) [1, 2]. For a long time, hard resins were considered useless in brewing, but recent studies delivered information that the hard resins positively contribute to the foam stabilising properties, impact all analysed attributes in sensory analysis and with increasing concentrations, higher bitter intensities were recorded [3, 4].

Alpha-acids (1.5-18% d.w.h.), also known as humulons, have the greatest importance in shaping the beer distinctive bitterness. The alpha-acids are the following compounds: humulon, cohumulon, adhumulon and alpha-acids are formed in result of the transformation of beta-acids (2.5-8% d.w.h. into lupulon, colupulon, adlupulone) during the maturation of the plant. This reaction is closely dependent on environmental conditions. With sunny weather during the summer months more beta-acids are transformed into alpha-acids than during the rainy and cold summer. The ratio of alpha-acids to beta-acids can range from 0.5 to about 4. Not all alpha-acids favorably affect the quality of bitterness in the beer. Such more intensive bitterness is delivered by cohumulone, therefore, cultivation methods aims to maintain the cohumulone level not more than 25% of the total content of alpha-acids in aroma hops and 35% in bitter hops. Insoluble alpha-acids are converted with high temperature into soluble iso-alpha-acids (isohumulone, isocohumulone, isoadhumulon), giving the beer a bitter taste [1, 2].

Bitter substances beneficially contribute to the persistence of foaming due to surface tension reduction. Also exhibit a bacteriostatic activity, however, not large enough to effectively raise the microbial durability of beer. Alpha-and beta-acids are unstable substances, which are constantly changing in the conditions of high temperature, humidity and oxygen availability. It is estimated that during storage in temperature of 18 °C during 2 months around 25% of alpha-acids may be further converted and product of the oxidation of both alpha- and beta-acids are hard resins. It is worth noting that their further conversion of hard resin may lead to the formation of valeric acid, which gives the beer an intense smell of cheese. In view of the above, extremely important for appropriate storage conditions of hops is avoiding access of air in the dry and cooled stores [1, 2, 3, 4].

Hop oils in hops occur in quantities from 0.5 to 4% d.w.h. This is a complex combination of different volatile substances. Their composition is varietal characteristic distinct for individual species of hops. Hop oils in 50-80% consist of hydrocarbon compounds (monoterpenes like myrcene; sesquiterpenes like caryophyllene, humulen, farnesene; aliphatic hydrocarbons like pentane or octane, in 30% of oxidised compounds (terpenic alcohols like linalool, geraniol; oxidized sesquiterpenes like epoxides, alcohols; others like aldehydes, esters, ketones) and about in 1% of sulfur compounds [2, 5]. The Table 1 presents classification of hop oil.

Table 1. Hop oil classification

hop oil		
hydrocarbons	oxygenated compounds	sulphur-containing compounds
monoterpenes (myrcene)	terpene alcohols (linalool, geraniol)	thioesters
sesquiterpenes (beta-caryophylene, farnesene)	sesquiterpene alcohols (humulenol I+II, humulol)	sulfides (DMS)
aliphatic hydrocarbons	others (alcohols, epoxides, ketones, esters)	other sulphur compounds

Source: Own work based on [6]

The component with the highest content in essential oils (20 – 70%) is volatile and very susceptible to oxidation is the monoterpene myrcene. Threshold of perceptibility for myrcene in the beer is about 120 µg/l. Its concentration in beer (ranging from 0 to 200 µg/l) with other more or less volatile constituents of essential oils, depends not only on their individual content in essential oils of hop varieties, but also from the size of the administered hops dose and the regime of hopping [2].

Dry-hopping methods significantly raise the aroma substances content in beer. Myrcene provides to beer the very wide spectrum of taste and flavours from the strongly resinous pine, herbal, grassy to an aromatic citrus and floral [2]. These flavour features can be disrupted by the presence of oxidized myrcene derivatives resulting during traditional hop boiling [2]. These compounds form the unpleasant oxidative taste of beer [2].

Also, other significant components of essential oils (e.g. sesquiterpenes like humulen and caryophylene) undergo oxidation in hops, but their oxidative derivatives are compounds with beneficial effects on the quality of the flavor characteristic in the beer. Those oxidation phenomena are strongly limited during dry hopping but it is worth mentioning that those oxidised derivatives of myrcene (and other ingredients of essential oils) are primarily formed during the processing and storage of hops conditions [2].

The most important and crucial compound forming a hop aroma in beer, and, in particular, the pleasant citrus, floral and fruity notes is the terpene alcohol linalool; especially when it appears in beers at concentrations above its threshold of perceptibility (27 µg/l). Another sensory beneficial terpene alcohol - geraniol with threshold of perceptibility of 36 µg/l provides the beer the floral and citrus scents, likely alpha - terpineol, who is related to creating the taste of resin [2].

It has been shown that during wort fermentation the yeast of the genus *Saccharomyces* converts the aromatic hop compounds such as eg. linanool or geraniol to other aroma compounds such as citronellol (responsible for a pronounced citrus aroma of beer) or alpha-terpineol [7, 8, 9]. Alpha-terpineol significantly complements the noble hop aroma in the beer composing greatly with sensory beneficial sesquiterpenes of essential oils like caryophylene, humulen and farnesene, which are components of high content in essential oils of many hop varieties and bring the beer the resin, herbal and spicy scents. All these components and other esters, aldehydes and ketones of essential oils as well as products of fermentation of beer, have a smaller or a larger contribution in the formation of hop scents. In beers of top and bottom fermentation they differ due to the qualitative and quantitative variations of the fermentation by-products [5].

The classic hopping methods in brewing industry

A classic approach for the use of hops in beer production is its addition during the boiling of wort. The varieties of highly content of bitter hops with high amount of alpha-acids should be introduced into the boiling process

at the beginning while the highly aromatic hop varieties should be added on the last 0-10 minutes. Boiling hops with the wort is followed by dissolution of the hop resins (mainly alpha-acids) and their isomerisation to the iso-alpha-acids, resulting in the formation of characteristic bitterness in the beer. Dissolution are also subjected the essential oils of hop which are responsible for the formation in the beer of distinctive hop aroma. The introduction of hops at the end of the cooking process results in extraction of essential oils from hops and their preservation in the wort. The type of aroma is less stable and could be seriously weakened after pasteurisation of beer (mainly after tunnel pasteurisation); relatively quickly disappear also during beer storage [10].

Other techniques of hops use during brewing (mash hopping, hop tea, hop back, first wort hopping, hop extracts, cold hopping)

As a result of the search for specific hop derived sensory characteristics of the final beer, apart from classic approach of the hops use in brewing, there are many techniques and methods of using hops at different stages of the production of beer. They all are focused on one common goal - obtain gentian and extraordinary hop flavour.

One of such methods is First Wort Hopping - FWH. This method involves adding hops to first wort, during lautering. This is a way to obtain very delicate, pleasant bitterness of beer and noble hop aroma. Another method is the mash hopping - MH, which is based on adding a part of the aromatic hops already at the stage of mashing. This treatment is designed to deliver to beer the hop taste and appropriate hop variety aroma. Hopping method based on adding hops to the wort after the end of cooking in a tank called whirlpool (swirling wort during cooling) when the temperature is less than the approx. 80 °C and higher than 60 °C. The use of such parameters impedes isomerisation of alpha-acids and facilitates dissolve the aromatic oils in wort. Hop back hopping involves passing of warm wort by the special device filled with hops. This way hopped beer increases aroma. Hop Tea hopping procedure is a method that involves hops infusion in the water or in a serving of wort and the addition of such infusion into the final beer [11].

Dry hopping

Dry hopping method is based on addition of hops to beer during lagering. This technique is designed to give to final, strongly hopped beer much more intense aroma. The resulting effect is different than when aromatic hop varieties are added at the end of the wort boiling. The differences in final effect between these techniques of adding aroma have been verified applying hops metabolomics [12, 13]. During dry hopping the alpha-acids are not isomerised so this method causes a negligible probability of increasing bitterness during fermentation. However, it has been shown that low alcohol content in beer allows the extraction of polyphenols and other compounds during the dry hopping, which to a small extent can contribute to increase the bitterness of beer [14, 15].

Slight increase in bitterness in the beer is not the essence of this technique. Dry hopping primarily is used to increase the extraction of essential oils and other aromatic compounds from hops to impart hoppy aroma to beer. Hoppy aroma is dependent on the characteristics of the used hops and can introduce to beer the resin, spicy, herbal, fruity, citrusy, earth or other scents. The popularity of this method is noticeable especially in craft breweries around the world which, unlike big breweries, produce beers in a variety of styles not only lager type beer, using new varieties of aromatic and gentian hops. It is worth mentioning that it is believed that this technique comes from the UK, however, the resurgence of the popularity of this method occurred in craft breweries of United States. Due to the fact that dry hopping takes place at relatively low temperatures, thermal degradation and loss of the aromatic substance are significantly reduced. This allows obtaining of a higher concentration of these compounds in the finished beer [10]. In addition, the dry hopping can intensify the impression of bitterness due to interactions with the hoppy aroma, increases the polyphenol content in beer, affect colloidal stability of beer, improves the stability of taste, increases the stability of foam, and provides more drinkability of beer [16].

Dry hopping methods

The traditional dry-hopping

Dry hopping as the technology draws increasing attention especially within craft and home breweries. Usually whole hop cones, ground hops or pellets are infused into cold beer to transfer in particular aroma components

with low losses (no evaporation) and reduced chemical transformations. This technique is still novel and there are a few statements available on the technology and technique of dry hopping [17]. Grinnell [17] emphasises the particular difficulties exists with reproducible transfer of hop substances with dry hopping. Also scaling up leads to several problems with aroma and flavor lost [18].

Dry hopping is usually accomplished by dropping hops directly or in special hop-bags into the fermentation tank from the top hatch (Fig. 1). Another way is pumping green beer from primary fermentation tank into a sterile secondary maturation and storage tank or very seldom from secondary into tertiary fermentation tank with hop-bags (Fig. 2). Unfortunately, these classic approaches lead to many technological problems.

The addition of hops in the bags reduces the contact of hop cones or pellets with beer, so with this solution, it must reconsider the poor performance of hop oils and aromatic compounds extraction into beer. Additionally, particles of hops passing the mesh of the bag can result in large beer haze and finally in its gushing.

Figure 1. Hop bag addition into fermentation tank.
Source: own work based on [11]

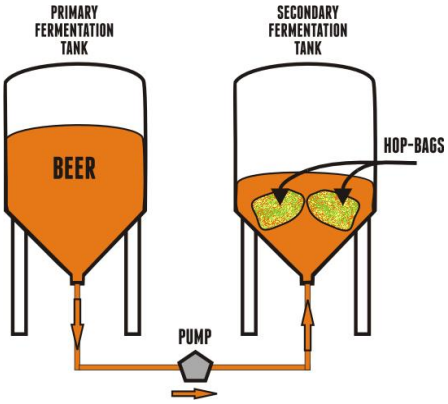

Figure 2. Hop bag addition into secondary fermentation tank.
Source: own work based on [11]

Novel dry hopping systems

Solving problems of extra hop aroma adding to the beer has led to various modern dry-hopping procedures such as hop cannons, torpedoes or hop rockets. Hop cannons utilise pressurised CO2 as transportation force to move hop pellets through the connected pipe into the top of the fermentation tank (Fig. 3). Hop cannons are designed as pumping device pushing beer through a hop bed and countercurrently extract significant hop aroma and flavour (Fig. 4). These processes reduce the possibility of dissolved oxygen uptake and prevent further oxidation. The all methods used for hopping after boiling aim in exhaustive extraction of hop cones leading to recovery of all the essential oils flavouring beer.

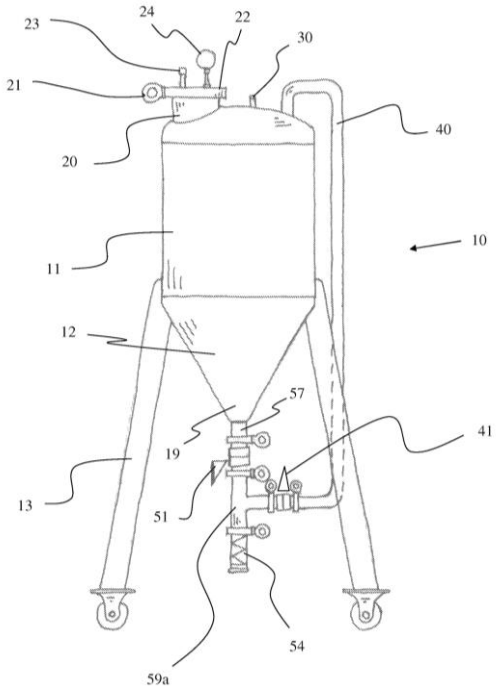

Figure 3. Diagram of a hop cannon. 10 – hop cannon, 11 – main body, 12 - a cone shaped lower end section, 13 – legs with wheels, 19 – exit port , 20 – material port, 21 – hinge, 22 - lid plate, 23 – fluid connection, 24 – pressure sensor , 30 – release valve, 40 – bypass pipe, 41 – bypass valve, 51 – material valve, 54 – sight glass , 57 - material pipe, 59a - middle branch of the tee.
Source: based on [19]

HopGun system from Braukon is also widely used. After filling HopGun tank (1) with cones of hops or pellets during the phase of dry hopping the contents of the tank circulates (2) until the saturation of hop flavourings reaches the required degree. Valuable hop oils and aromas are released and then the suspension is back by a specially designed perforated internal candle of HopGun tank. Insoluble particles of hops are retained in the tank (Fig 4. part 3).

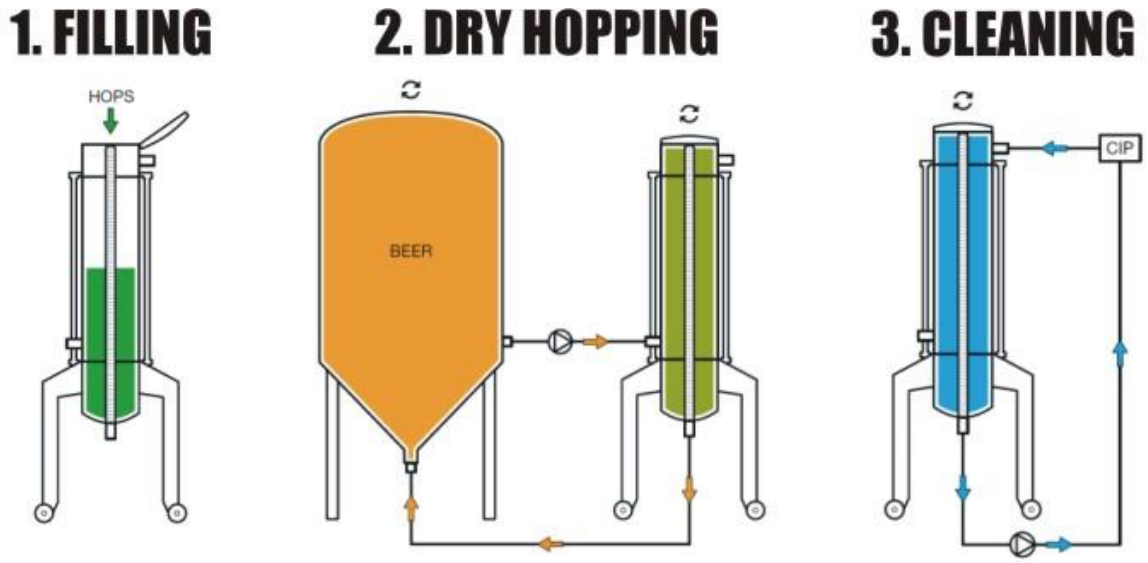

Fig. 4. HopGUN system procedure.
Source: http://braukon.de [20]

Other supportive actions as additional milling are designed for enlarging the efficacy of dry hopping. One of them is ROLEC DryHOPNIK system using an external milling for hop dispersion in an external loop of green beer. The loop is pressurised to avoid overfoaming and related beer loss. An inert gas - CO_2 is injected to tank with hop to avoid oxygen pick-up. One batch of hop pellets fills the hop dosing vessel. Milling chamber serves also as mixing tank, so further mixing with beer is not necessary [21].

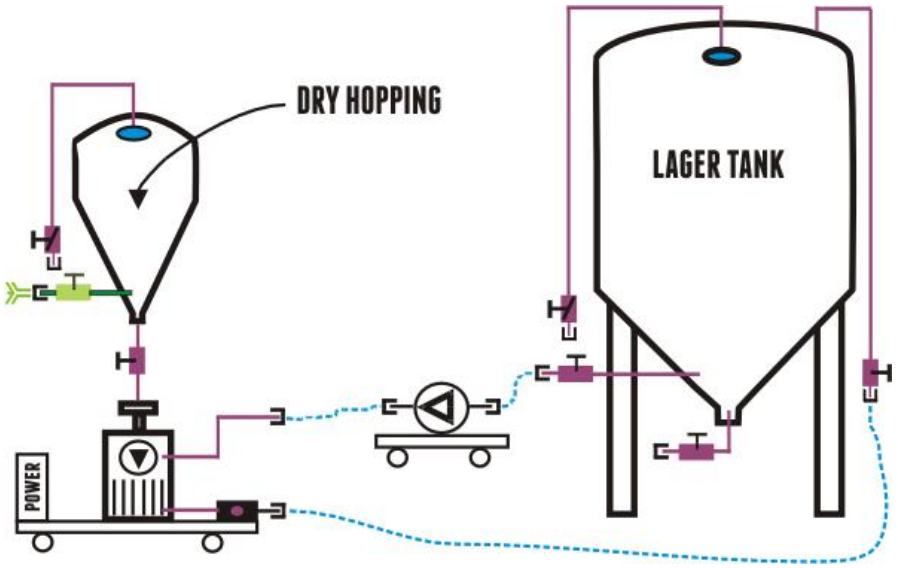

Figure 5. Rolec-DryHOPNIK System.
*Source: www.**rolec**-prozess-brautechnik.eu [21]*

Comparing those solution it has to be noted that the problems rising from reduced contact between hops and beer which appears in traditional solutions using bags and resulting poor extraction yield was solved with fixed bed of hops which is used by hop cannons (Fig.3). The increase of such extraction was obtained and controlled with circulation of beer through perforated internal candle of HopGun system (Fig. 4) . Enlargening scale of dry hopping with exhaustive extraction was obtained during additional milling of hops and mixing within DryHOPNIK system (Fig.5).

Summary and conclusions

The popularity of the dry hopping methods, launched through the development of craft brewing in the United States, so far brings many benefits in brewing technology. It has developed the science of hops use technology and led to better understanding of aromatic compounds of hops. The responsible for the citrus flavour of beer is supposed to be (among others) beta-citronellol, which is the result of bioconversion of geraniol due to metabolism of yeast and synergistic action of linalool with geraniol and citronellol. This knowledge have started continuous research on new varieties and hybrids of gentian and aromatic hops application. Gradually they are placed on the market and described as new hops. Most of all new varieties over the past few years, was cultivated in the United States, Germany, Australia and New Zealand.

The elimination of technological problems resulting from the application of classical methods of the hopping led to the creation of compact solutions performing enhanced extraction of essential oils and hops aroma in beer while reducing the consumption of hops (up to 50%) [2]. Device types as Hop Gun, Hop cannon, Torpedoes, DryHopnik Systems and other are mobile devices that can handle all the tanks at the brewery, regardless of their location. Thanks to this breweries save space and money avoiding solutions where intermediate tanks are required for the extraction of hops.

Dry hopping method has several advantages, both economical and sensorial. Despite the mobility and space saving design, also the process of hopping during fermentation deserves better attentions. As it is often performed during active fermentation – the yeast capable of metabolising hop derived component significantly contribute to development of novel flavourings.

Their transfer rates of hop substances during dry hopping which can provide a great variability of application is still not well elaborated. Forster [17] showed that from the all α-acids dosed to beer only 4 to 5% can be found in the beers, of the total polyphenols 50 to 60% and of the low-molecular polyphenols 60 to 70%, while terpene hydrocarbons reveals yields of about 3%; linalool transfers to about 100% and geraniol seems to react variety-specific. Geraniol seems to be converted during dry hopping and released also from geranyl acetate achieving finally total yield (from geraniol and geranyl acetate in hops) from 36% to 62% [22].

It can be said that this biotransformation has massive impact on dry hop flavour. The literature provides information that only terpenoids undergo biotransformation and there exists no published evidence of the transformation of myrcene, humulene, or caryophyllene. While these hydrocarbon terpenes are not converted, the yeast act as the agent and remove them from solution. Takoi et al. showed that geraniol is metabolized by yeast into β-citronellol rapidly during the primary fermentation in 2-4 days after beginning [8]. Other work showed the bioconversion with yeasts of geraniol to β-citronellol is also accompanied by the by stream synthesis of geranyl acetate and citronellyl acetate [6]. King and Dickinson elaborated the scheme of biotransformation of geraniol and nerol by *S. cerevisiae* for 4 possible outcomes: citronellol, linalool, α-terpineol, and terpin hydrate [7]. This works reveal the huge aroma shaping capacity of dry hopping during lagering.

Additionally innovative solutions of dry hopping systems can also be used for the extraction of flavouring substances from other raw materials e.g. fresh, frozen or dried fruits, spices, oak flakes etc. Relatively small and mobile devices allow very diverse exploitation limited only by resulting sensory characteristic of beer.

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