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Abstract: The paper presents a prototype of the integrated decision support system DECWASTE developed to support decision making in waste management in the Czech Republic. It uses linked open data of eGovernment systems of the Czech Republic. It consists of six sub-modules: PARSER, which downloads the appropriate data from the eGovernment systems to its databases; PREVENT, which calculates the prevention impact on waste generation; FORECAST, which forecasts waste generation for a given time period using developed mathematical forecast models based on the DPSIR (Driving forces-Pressures-States-Impacts-Responses) framework including past time series of waste stream generation; TREATMENT, which forecasts waste treatment for the given time period using FORECAST waste generation outputs and respects the legislation requests; INVEST, which calculates required investment in the treatment facilities forecast by TREATMENT and the OUTPUT sub-module, which visualizes and presents different scenarios for decisionmakers depending on input data of the PREVENT, FORECAST and TREATMENT sub-modules. The paper briefly describes information and communication technologies used in applied eGovernment systems and the integration of sub-modules PARSER, PREVENT, FORECAST, TREATMENT, INVEST and OUTPUT into the complex decision support information system DECWASTE in details.

***Keywords**:* waste management; decision support; eGovernment; integrated information system; modelling

1 INTRODUCTION

Waste is an unavoidable by-product of anthropogenic activities. Solid waste produced as a by-product of our daily activities poses a major threat to societies as populations grow and economic development advances. Turning waste into a resource is one of the keys to Circular Economy (EC, 2014, 2015) in the European Union (EU).

Waste management planning is the cornerstone of any national, regional or local policy on waste management for decision making authorities. It needs appropriate and efficient information and communication technologies (ICT) tools (Arena, Di Gregorio, 2014). An obligation results from the EU Waste Framework Directive to create and maintain the Waste Management Plan (WMP) as an essential strategic document. It shall contain an overview of the current state of waste management, definition of the objectives to be met, and it also formulates strategies and identifies the need for implementation of means, including the decision support systems (DSS).The drawing up of WMPs is an obligation of the EU Member States (MS) and is required by Article 28 of the *Waste Framework Directive* (WFD) (EC, 2008). In order to assist national, regional and local competent authorities in preparing WMPs in line with the WFD requirements, the European Commission (EC) has published a methodological *Guidance Note* (EC, 2012) where ICT support and specified framework for DSS are considered. In order to move up the waste hierarchy, the WFD requires that MSs establish *Waste Prevention Programmes* (WPP). All the above requests had to be considered within the DSS design (Kamperis et al., 2013; Stefanovic et al., 2015; Sevigne-Itoiz et al., 2015). Decisions in waste management are not only very capital-intensive but also difficult from environmental, economic and social points of view. There is the need to develop, master and implement a simple but reliable DSS that will help decision makers at national, regional and local levels to analyse waste management processes, follow national legislation and WFD implementation, further the framework of WMP and WPP for the given level and consider the EU Circular Economy tasks.

The paper discusses the development of the prototype DECWASTE, the complex DSS for waste management on the national level of the Czech Republic. It will assist in identifying alternative waste management strategies and support the national WMP and WPP that meet the objectives of the EU WFD and Circular Economy.

The first part of the paper introduces the history of environmental information and decision support systems since 1992. The second part of the paper is devoted to linked open data in eGovernment of the Czech Republic, which are a necessary input to DECWASTE. Its sub-modules PARSER, PREVENT, FORECAST, TREATMENT and INVEST are introduced in the third part of the paper. The OUTPUT sub-module of DECWASTE, which visualizes and presents different scenarios to decision makers, is described in the fourth part of the paper.

2 HISTORY OF DECISION SUPPORT SYSTEM FOR WASTE MANAGEMENT

National environmental data facilities and services are part of the environmental information systems (EIS) of the Ministry of the Environment (MoE) of the Czech Republic and have been developing since 1990. EIS on the national level have been developing within the framework of the United EIS of the Ministry of the Environment (MoE) of the Czech Republic and the Czech Environmental Information Agency (CENIA) since 2002 and they systematically collect primary environmental data through monitoring, statistical research and annual reporting (Hřebíček, Kubásek, 2011; Prášek et al., 2013; Soukopová et al., 2015).

Development of the DSS concerning waste management on the national level for MoE began in 2008, when Hejč and Hřebíček (2008) published the general model to forecast waste generation on local, regional and national levels. Soukopová and Hřebíček (2010, 2011) continued in this research and developed an integrated economic-mathematical model of municipal waste management of the Czech Republic.

Multidimensional regression methods and the mathematically applicable waste streams structure model were used to develop the new complex model of MSW management (generation and treatment) of the Czech Republic (Kalina et al., 2014; Soukopová et al. 2014). This model was developed also for the purposes of the MoE. It was used by decision makers on the national level in development of the national WMP, national WPP strategies and support of sustainability of MSW management of the Czech Republic in accordance with the EU waste legislation.

The team of authors has reviewed plenty of waste information systems and modelling approaches identified in (Hung et al., 2007; Beiglet al., 2008; Mazzanti, Zoboli, 2008; Pires et al., 2011, Lebesorger, Beigel, 2011; Andersen, Larsen, 2012; Rimaityte et al., 2012; Waste model, 2012; Hill et al., 2014; Secondi et al., 2015) and aimed at explaining or estimating the present or future waste generation and treatment using economic, socio-demographic or management-orientated data. It also analyzed potential sources of linked open data in eGovernment of the Czech Republic.

3 LINKED OPEN DATA IN EGOVERNMENT OF THE CZECH REPUBLIC

The current state of several national environmental, socio-demographic, economic, financial data facilities and services based on eGovernment implementation in the Czech Republic was published by Soukopová et al., (2015). These eGovernment systems provide sources of necessary input data for DECWASTE. Moreover, the related linked open data are often available on public administration (PA) web sites, such as those of the MoE, CENIA, the Ministry of Finance (MoF), the Ministry of Regional Development (MoRD), and the Czech Statistical Office (CZSO).

The MoF provides a specialized web information portal MONITOR (2013) that allows open public access to budget and accounting information from all levels of PA including every municipality of the Czech Republic. The information presented is updated quarterly. The primary version of MONITOR was released in May 2013. It replaced the previous web portals ARIS (2001) and ÚFIS (2011) (databases of the municipalities' accounting from 2000 to 2012) of the MoF.

The data concerning municipal areas and populations are also publicly accessible on the web portal of CZSO (CZSO, 2015) and in the RIS web portal (RIS, 2016) of the MoRD, where is data from the all municipalities of the Czech Republic.

4 NATIONAL WASTE MANAGEMENT INFORMATION SYSTEM

Environmental legislation of the Czech Republic requires organizations, companies and municipalities etc. (i.e. environmental reporters) to provide the PA on the regional level with annual data and information on their waste management activities (waste report). These waste reports are processed by the CENIA through the ISPOP - *Integrated System of Reporting* (ISPOP, 2016, 2016a) of the MoE, which was developed in collaboration with IBM between 2008 and 2013 (Prášek et al., 2013).
The basic idea of ISPOP is to provide a solution in the Adobe LiveCycle ES technology. Electronic smart forms are available in the PDF format and they are part of the XML layer for computer processing (ISOP, 2016a). The forms also include a PDF layer for the electronic signature, by means of which it is possible to authorize a document. Filling in the forms and browsing through them is possible by means of Adobe Reader (Soukopová et al., 2015).
For using ISPOP, the main technical requirement is a common internet connection. To work with ISPOP web applications, the user needs an internet browser an Adobe Reader.
ISOH - *Waste management information system* (ISOH, 2011; CENIA, 2016) of the MoE is a comprehensive information system built according to the principles of service-oriented architecture. ISOH is based on the Firebird relational database offering many ANSI SQL standard features that run on Windows. ISOH is operated on the Windows platform, blade server, CPU E5450 3GHz, RAM 6GB, HDD SCSI 200 GB, disk field raid 5.
Environmental reporters send their annual waste reports to ISPOP and ISOH then processes these reports. It is used for PA decision making, control and statistical needs in waste management. They insert the reports to ISPOP according to the Czech waste legislation in prescribed annual standards (ISPOP, 2016a). Each annual report is verified by the PA of its administrative region and sent to the central ISOH database which then generates a publicly accessible aggregated annual database (CENIA, 2016).

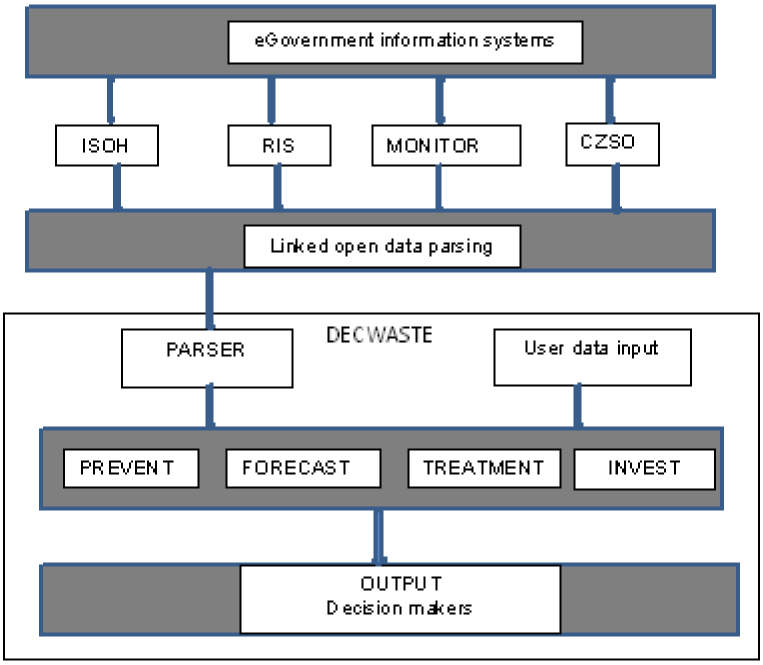

Figure 1.DECWASTE data flows and sub-modules. Source: authors

The ISOH contains data concerning waste generation and treatment by generators and facilities to treat, recover and dispose waste. Every year, ISOH records more than 70,000 different generators´ reports from all 6,500 municipalities of the Czech Republic and more than 3,000 facilities´ reports. The annual ISOH database contains more than 50,000 records of municipal waste generation and 10,000 records concerning their treatment (Soukopová et al, 2015).

5 DATA FLOWS AND SUB-MODULES OF DECWASTE

The architecture of the DECWASTE system and its sub-modules and data flows are shown in Figure 1. The input waste management data to DECWASTE are annually collected by ISPOP and, when processed in ISOH, they are imported by the PARSER sub-module to the DECWASTE MySQL database. Additional appropriate data are imported by the PARSER sub-module to the DECWASTE database from the MONITOR, RIS and CZSO web portals. We had to develop special parsers codes for these web portals to import appropriate data, which needs FORECAST, TREATMENT and INVEST sub-modules. Other appropriate data to these sub-modules input come directly from decision makers.

PARSER – parsing system sub-module

We describe the parsing system using an example of processing linked open data from the MONITOR system. The parsers for ISOH, RIS and CZSO were developed in similar ways and we will not describe them because of the limit concerning the number of pages in the paper.

The processing of the MONITOR linked open data can be divided into five phases: *definition of appropriate data; data export; data processing; data import* and *data optimization*.

We have used the MONITOR analytical part to define the appropriate data. When entered, the parameters identifying the appropriate data (e.g. year, paragraph, given value) were exported to XLS format in Windows and stored in a single CSV file which could be exported to the MySQL database of DECWASTE. The parser file GeneratorDat.py was created in language Python, which exported the data to DECWASTE database. It saves the parameter (e.g. year, paragraph, value) in the database if it has some value. On the contrary, if it has no value, the parser saves the value associated with the parameter with the value from the last parser.

The annual data downloaded from the MONITOR were subsequently modified to the desired format and uploaded by the parser to MySQL database which had to be optimized. It includes entities concerning all municipalities connected with their municipality with extended powers (MEP), district and region geographic specification.

PREVENT - Prevention waste sub-module

PREVENT calculates prevention impact on waste generation. PREVENT was developed for MSW. It assumes that MSW prevention follows the municipal WMP and WPP impact and mostly depends on two factors: *the number of people/households* participating in the WPP; and the *amount of waste* prevented by each participant.

Each WPP initiative could estimate the amount of waste that is likely to be prevented if it were to be implemented. Naturally, the number of participants involved and the amount of waste prevented will depend on a number of other factors, for example, the type of WPP initiative, the socio-economic demographics of the target population and the degree to which the WPP initiative is promoted by PA (Daskalopoulos et al., 2008). The outputs of PREVENT are expressed as percentages of an estimated amount of waste that is likely to be prevented if it were to be implemented given the WPP initiatives.

FORECAST – Waste generation forecasting sub-module

FORECAST is a waste generation forecasting sub-module. It forecasts the amount of waste generated on the national level for a given time period and chosen waste streams *f* (consisting of chosen waste codes of the European list of waste). It was developed through the mathematical forecast models based on DPSIR (Driving forces-Pressures-States-Impacts-Responses) framework predictors (Horáková et al., 2015), following models (Andersen, Larson, 2012; Kalina et al., 2014; Soukopová et al., 2015). It uses available linked open data of DPSIR predictors from eGovernment systems and past waste generation from ISOH (from the period 2009 to 2014) stored in the DECWASTE database.

Let us assume that for every waste stream *f* the amount of waste $\hat{w}_t^f$ is known as well as "predictors" $\hat{A}_{i,t}^{f}$, i=1,…, K^f; t=2009,…,2014, then the waste stream generation $w^f(t)$ in the given year *t* for every waste stream *f* fulfil the equation

$$\log(w^f(t)) = a_0^f + \sum_{i=1}^{K^f} a_i^f \cdot \log\left(A_i^f(t)\right) + \varepsilon_t^f, \quad (1)$$

where $A_i^f(t)$, i=1,…, K^f are predictors in the given year *t* derived from the DPSIR analysis of the waste stream *f* (Horáková et al., 2015) and $\varepsilon_t^f = \log\left(w^f(t)\right) - \log(\hat{w}_t^f)$, t=2009,…,2014 are approximation errors. The coefficients $a_0^f,\dots,a_K^f$ in (1) for each waste stream *f* are calculated using multiple regression on the basis of the values of waste generation $\hat{w}_t^f$ a predictors $\hat{A}_{i,t}^f$, i=1,…,K^f; t=2009,…,2014. Approximation errors ε_t^f t=2009,…,2014, have the mean equal to 0 and normal distribution.

If we want to establish the confidence interval of predictors $A_i^f(t)$, it will be necessary to restrict their number to $K^f \leq 4$, since we only have a time series of six known values. As soon as we know the

values of $\hat{w}_t^f$ and $\hat{A}_{i,t}^f$ for the next years *t*=2015,…, entered to the model (1) will be more accurate and the approximation error $\varepsilon_t^{f,ps}$ smaller.
Furthermore, we assume that the predictors $A_i^f(t)$, *i*=1,…,K^f, for *t*=2015,…,2024 have either known published values (GDP, population, household consumption, etc.) or are determined by an appropriate extrapolation method or are chosen manually as input to FORECAST.
The FORECAST sub-module is written in language R and uses predefined predictors $\hat{A}_{i,t}^{f,}$ (Horáková et al., 2015) from the DECWASTE database, which has been parsed from linked open data. Its output $w^f(t)$ is a time series of the amount of generated waste for *t*=2015,…,2024 of waste stream *f* stored in the DECWASTE database.

Step 2: Expectations of future development 2024

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	
Household expenditures for food, clothes anfd shoes [bil. CZK]	589.9733	595.4104	600.8475	606.2846	611.7216	617.1550	622.5920	628.0291	633.4662	638.9033	Source: https://vdb.czso.cz/vdbvo2/faces/index.jsf?page=statistiky#katalog=30847
Mid-year population [thousand of inhabitants]	10538	10534	10531	10527	10524	10520	10507	10493	10480	10467	Source: https://www.czso.cz/csu/czso/obyvatelstvo_hu
Number of retired [thousand of inhabitants]	2884	2848	2843	2838	2833	2828	2823	2818	2813	2808	Source: http://www.cssz.cz/cz/o-cssz/informace/informacni-materialy/statisticke-rocenky.htm
Unemployment [%]	6.6	5.9	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	Source: https://vdb.czso.cz/vdbvo2/faces/cs/index.jsf?page=vystup-objekt&pvo=ZAM06&zo=N&z=T&f=TABULKA&verze=-1&nahled=N&sp=N&filtr=G~F_M~F_Z~F_R~F_P~_S~_null_null_&katalog=30853&str=v95&c=v3__RP2014
1st prevention measure (effect) [% of MSW generated]	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	
2nd prevention measure (effect) [% of MSW generated]	0	2	5	9	14	20	27	35	44	9	
3rd prevention measure (effect) [% of MSW generated]	0	3	6	9	12	15	18	21	24	27	

Insert values into the model

Figure 2. Step 2. Expectation of future development in MSW generation Source: authors.

TREATMENT - waste treatment forecasting sub-module
The TREATMENT sub-module forecasts appropriate waste treatment for every waste stream *f* and time period *t*=2015,…,2024 using FORECAST outputs concerning forecast waste generation $w^f(t)$ and fulfilling the EU and national waste legislation requests. Kalina et al. (2014) and Soukopová et al. (2014) developed a system of nonlinear equation for the TREATMENT sub-module solution and used Maple to solve this nonlinear system analytically. Its outputs are the amounts of appropriate waste treatments (material recycling, energy recovery, composting, landfilling and disposal) of the total quantity of generated waste stream $w^f(t)$. We will not repeat a detail description because for calculation of waste streams $w^f(t)$ it is similar to that of the municipal waste stream and we are limited by the number of pages.
INVEST – a sub-module to calculate the investment required
The special INVEST sub-module calculates required investment in treatment facilities which are necessary to cover the amount of waste stream $w^f(t)$ forecast by TREATMENT for the given treatment. It was developed by Hřebíček and Soukopová (2010), and in detail it was described by Soukopová and Hřebíček (2011) for the municipal waste stream and modified by Hřebíček et al. (2013) for the general waste stream $w^f(t)$. This integrated economic-mathematical model is a balanced network model for a set of waste stream $w^f(t)$ sources connected with a set of chosen waste treatment facilities processing this waste stream. The model involved energy recovery, material recycling, composting, and landfilling. It was implemented as a combination of four further sub-models (GIS transport sub-model, TREATMENT sub-model, cost economic sub-models of all treatment facilities and a sub-model optimizing greenhouse gases expressed as the CO_2 equivalent) and it is easily scalable.
OUTPUT sub-module
We integrate outputs of the above sub-modules into one sub-module OUTPUT written in the R software environment, deploying Shiny package that makes it easy to build interactive web applications (apps) directly from R.

There are several distinct branches of the output interface, devoted to the individual waste streams $w^f(t)$ and represented by independent server scripts (server.R files and ui.R presentation layers). This ensures complete scalability by adding or removing scripts for other waste streams $w^f(t)$. In the current version of the output interface, 18 waste streams (MSW, biowaste, car wrecks, hazardous waste, WEEE and other streams) are available with an arbitrary number of possible other ones (Horáková et al., 2015).
The OUTPUT interface is built as a pre-filled form with previously created scenarios proposed by MoE decision makers in downloadable .csv files containing all desirable inputs of PREVENT, FORECAST and INVEST and outputs of the scenarios.

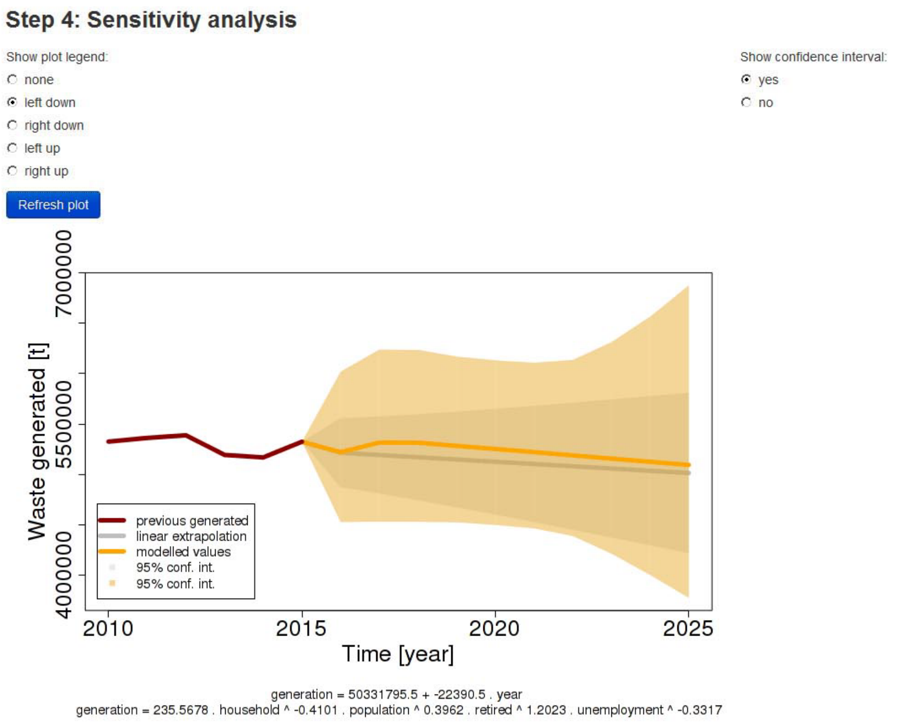

Table of model outputs (in logarithmic form):

Predictor	Degrees of freedom	Sum of squared residuals	F statistics	p value
Variable: household	1	0.000324	6.3	0.241
Variable: population	1	5.3e-05	1	0.494
Variable: retired	1	2.6e-05	0.5	0.606
Variable: unemployment	1	0.001039	20.3	0.139
Residuals	1	5.1e-05		

Figure 3. Step 4. Sensitivity analysis of MSW generation forecasting. Source: authors

6 MUNICIPAL SOLID WASTE FORECAST GENERATION ANALYSIS OUTPUTS

The OUTPUT sub-module consists of control functions, graphical and numerical outputs, representing four basic output steps for waste stream generation. We present two of them for MSW.
In the first step, there are boxes of basic data inputs over a time *t*=2009,…,2014 for modelling: previous MSW generation and time series of the known values of relevant DPSIR analysis predictors (implicit values are parsed by PARSER) and FORECAST outputs.
In the second step (Figure 2), decision makers can specify expected values of the predictors (pre-filled values are available with hyperlinks to data sources) in the model (1), or choose their possible linear/exponential extrapolation. Decision makers can also input expected prevention measures of the PREVENT sub-module (three possible scenarios of MSW prevention are available).
In the third step, results are shown in a form of a table, mathematical expression of (1) and a time-plot, showing the future MSW generation development and effects of the prevention measures taken (curves representing the prediction interval and shaded areas of confidence intervals).
In the fourth step (Figure 3), a sensitivity analysis is presented, showing decision makers an estimated effect of the individual predictors from the model (1) and the quality of forecasting.

CONCLUSION

The prototype of DECWASTE - the complex DSS for waste management on the national level of the Czech Republic has been introduced. It supported the development of the national WMP and WPP in 2014 to meet the objectives of the EU WFD and Circular Economy.
DECWASTE uses linked open data of the Czech Republic eGovernment systems, which is necessary for its sub-modules: PARSER, PREVENT, FORECAST, TREATMENT and INVEST which have been also shortly introduced. Two outputs (Figure 2 and Figure 3) of OUTPUT sub-module of DECWASTE are presented for MSW flow. OUTPUT was used by decision makers of the MoE to visualize and present different scenarios of waste management based on WPP initiatives.

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