The Message model description

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The Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE) is a dynamic linear energy model generator developed by the International Atomic Energy Agency (IAEA). MESSAGE combines technologies and fuels to construct so-called ‘energy chains’, making it possible to map energy flows from resource extraction, beneficiation and energy conversion (supply side) to the, distribution and the provision of energy services (demand side). The model can help to design long term energy supply strategies or test energy policy options by analysing cost optimal energy mixes, investment needs and other costs for new infrastructure, energy supply security, energy resource utilization, rate of introduction of new technologies (technology learning), and environmental constraints.

MESSAGE is designed to formulate and evaluate alternative energy supply strategies consonant with user defined constraints on new investment, market penetration rates for new technologies, fuel availability and trade, and environmental emissions. The underlying principle of the model is the optimization of an objective function (e.g. least cost, lowest environmental impact, maximum self-sufficiency) under a set of constraints.

The backbone of MESSAGE is the techno-economic description of the modelled energy system. This includes the definition of the categories of energy forms considered (e.g. primary energy, final energy, useful energy), the fuels (commodities) and associated

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1 The aim of this text is to describe the basic characteristics of MESSAGE model generator which was used at the Charles University to developed Czech and Slovak energy models. The text is based mainly on IAEA (2002) Model for Energy Supply Strategy Alternatives - User Manual, but is it focused on the model’s attributes used by the Charles University.
technologies actually used (e.g. electricity, gasoline, ethanol, coal, district heat), as well as energy services (e.g. useful space heat provided by type of energy/technology). Technologies are defined by their inputs and outputs (main and by-products), their efficiency and their variability if more than one input or output exists, e.g. the possible production patterns of a refinery or a pass-out turbine. Economic characteristics include investment costs, fixed and variable operation and maintenance costs, imported and domestic fuel costs and estimates of levelized costs and shadow prices.

Fuels and technologies are combined to construct energy chains, where the energy flows from supply to demand. The model takes into account existing installations, their vintage and their retirement at the end of their useful lives. The investment requirements can be distributed over the construction time of a plant and can be divided into different categories to reflect more accurately the requirements of industrial and commercial sectors. The requirements for basic materials and for non-energy inputs during construction and operation of a plant can also be accounted for by tracing their flow from originating industries either in monetary terms or in physical units. For some fuels, ensuring timely availability entails considerable cost and management efforts. Electricity has to be provided by the utility at exactly the same time it is demanded, and MESSAGE simulates this situation.

Environmental aspects can be analysed by keeping track of, or limiting, pollutants emitted by various technologies at each step of the energy chains. This helps to evaluate the impact of environmental regulations on energy system development.

The most powerful feature of MESSAGE is that it provides the opportunity to define constraints for all types of technology. The user can, among other options, limit one technology in relation to other technologies (e.g. a maximum share of wind energy that can be handled in an electricity network), give exogenous limits on technologies (e.g. a limit on cumulative SO2 or greenhouse gas emissions). The model is extremely flexible and can be used to analyze energy and electricity markets and climate change issues.

The model is able to simulate and optimise an energy system from resources mining or import to the final demand. In the current version of MESSAGE used at the Charles University, there are no cycles in the model and the resultant values do not enter back into the model. This means that the model cannot simulate the reaction of demand on price changes. Demand is one of the main inputs into the model.
On the other hand the model is very detailed. MESSAGE is designed to formulate and evaluate alternative energy supply strategies consonant with the user-defined constraints such as limits on new investment, fuel availability and trade, environmental regulations and market penetration rates for new technologies. (IAEA, 2002 pp. I-3) The model includes also a possibility to calculate in the simulation with some regular demand fluctuations during a time period. There is a potential to differentiate day and night, winter and summer, etc. The model is then able to calculate the load curve and optimise the power plant’s inventory on this base.

In the results part MESSAGE shows not only the optimal (under entered premises) composition and structure of the energy system but we can choose any item from the model and the model shows us the development of the item (e.g., investment costs, fuel mix) and that for each power plant separately.

♦ **Input data and model structure**

The MESSAGE requires a considerable amount of input information in order to simulate the energy system so detailed. The main input data are technical and economic data of the technologies (e.g., potential fuel types, efficiency, capacity, emission factors, and investment costs), discount rate, fuel costs, energy demands and their trends.

Model database is made up of eight sections into which we put the data: General, Load regions, Energyforms, Demands, Constrains, Technologies, Storages and Resources.

In section **General**, the discount rate and years are the key data. By the years we set the time horizon of the case, number of periods to optimise and number of time steps for which activity and capacity variables are integer variables – length of the base time unit for optimise. The last model year we should set approximately twenty or thirty years behind our desired end year because the model needs to spread also the investments from the last years of our simulated time area. We set also the default units like currency, energy and power unit here.
The MESSAGE model allows modelling of variations in energy demand within a year with seasons, types of days or time of a day. This requires additional parameters to form the pattern of the energy demand, which is referred to as **Load regions** or load curves. (IAEA, 2002 pp. III-5) This means we can define any number of seasons in the year, types of day (e.g., workday, weekend or holiday) in each season and parts of each type of day. So if we wanted and had enough required data, we could simulate an energy system with exactitude on hours.

The basic structure of our simulated case we create in the section **Energyforms**. Here we define the energy level from end demand to over the production of heat and electricity to the fuel resources. We can make an energy level for trading with emission allowances too. We can simulate the trading with emission allowances on level of individual power plant (or heating plant) or for the whole energy system as a complex on this way. In each energy level we set the concrete energy forms. This means the concrete power plants, heat plants, fuels, types of demand, etc. To these prepared items we add their values and other parameters in the other model sections.

In **Demands**, we choose the single, in Energyforms predefined, demands and set their values. We have to do this with all demands and actually for all our load regions. The model gives us four choices how to define the demand’s escalation. They are adduced in the Table 1. On the same way we can set all parameters in the model by which it is needed - like all costs or constrains.

**Table 1 Types of Data Set**

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Constant</td>
<td>One data value for all the years in the case study</td>
</tr>
<tr>
<td>Time series</td>
<td>A set of values for the given number of model years in the case study. If numbers of values are less than the number of model years then the last value is used for the remaining model years.</td>
</tr>
<tr>
<td>Constant growth</td>
<td>A growth rate applied for all model period defined in the case study.</td>
</tr>
<tr>
<td>Periodic growth</td>
<td>A set of growth rates for the given number of periods in the case study. If number of values are less than the number of study periods then the last value is used for the remaining study periods.</td>
</tr>
</tbody>
</table>

There are four groups of constraints at our disposal in section **Constrains**: cumulative, cumulative per period, and two free undefined groups, which give us some latitude for our own specific needs. Here, we set for example the emission factors for each technology and fuel, emission limits, and also the possible payments for the emissions. The model gives us also the possibility to set unlimited numbers of types of payments and constraints for the emissions or other activities. We can define the upper and lower limit for all constraints. We set the unit costs for activity units and we can add penalties, either negative for the activity values below the lower limit or positive for the values above the upper limit. For each single penalty, we set its limit. There is created a range between each two limits on this way, in which the penalty is put on the base unit costs. This means the final price of the activity unit can be lower than base unit costs (or even negative) if the activity value ranges below the lower constrain limit of the activity. In the case that the activity value exceeds the upper limit, the unit costs rise by the penalty but only for the volume above the upper limit—the base unit costs for the remainder is unchanged. This way, we can receive a motivational scheme with graduated payments for any constrain which we put into the model.

**Section Technologies** has two parts: Activity and Capacity.

In Activity part, we set input and output flows in each technology (Imported fuels, electricity, or heat have no entry only unit costs and demands have only inputs—they close the energy chain.). We can add more than one input or output for each technology and change the proportion of the single inputs and outputs also. This way, we link all our energy forms linearly. With the proportion of inputs to outputs, we define the effectiveness of the given technology. In each technology, we can set variable activity unit costs and their escalation if any variable costs are created directly in this technology. There are all constraints from the section Constrains at our disposal and we can integrate them into the given technology. But the MESSAGE offers us even more constraints like Annual bounds on activity, Lag times for output fuels and materials, Bounds on activity or Market penetrations on activities.

The Capacity part is important mainly for new technologies and capacities which are not constructed yet—especially for the power plants, CHP or heat plants. In this section, we put into the model the capacity of the new technology unit (the model has to build the whole unit not only a part of it), the plant life, maximal availability of the technology per year.
or load region if it has a defined load region, but primarily the investment costs per unit of main output (in our case per MW) and construction time of the technology unit. We can also set the minimum utilization rate of the technology or fixed O&M costs per year – but these costs are only crude and in the most cases insignificant compared to the variation costs. The model allows us to restrict the new capacity addition per year, the cumulative installed capacity for given technology or market penetration of new capacities.

Figure 1 shows a schematic illustration of a general energy chain.

The **Storages** can be used for simulation of transfers of energy from one period to another (e.g., from night to day, from summer to winter). We should define similar parameters like in Capacity in section Technologies here – plant life, unit capacity, investment costs and construction time. Moreover we choose a type of storage - continuous, seasonal, annual, weekly or daily - and we set storage costs and technical parameters of the storage (e.g., maximal and minimal energy volume, storage losses).
In the section Resources we define the fuel cost multiplier – the relationship between resource cost and fuel cost – and the total resource extraction limit. The model allows us to define more product categories from the same resource. For each of product we set the resource cost, remaining resources and upper limit on annual extraction for given product. For each product we have all constrains from the section Constrains at our disposal and further we can set bounds on extraction for given product and market penetrations of the product.

♦ Types of Costs, Objective function and Discounting

The different types of costs (i.e. entries for the objective function) can be accumulated over all technologies in built-in accounting rows. These rows can be generated per period or for the whole horizon and contain the sum of the undiscounted costs. They can also can be limited. The implemented types are:

CCUR – fix (related to the installed capacity) and variable (related to the production) operation and maintenance costs,

CCAP – investment costs; if the investments of a technology are distributed over the previous periods, also the entries to this accounting rows are distributed (if the capital costs are levellized, the total payments in a period can be taken from CINV; CCAP shows the share of investments in the according period, then),

CRES – domestic fuel costs,

CAR1 – costs related to the user defined relation of type 1

CAR2 – costs related to the user defined relation of type 2

CINV – total investments (in case of levellized investment costs, see CCAP).

The objective function contains the sum of all discounted costs, i.e. all kinds on costs that can be accounted for. All costs related to operation (e.g. resource use, operation costs) are discounted from the middle of the current period to the first year. By using the facility of distributing the investments or accounting during construction these costs can be distributed over some periods before or equal to the current one. This distribution can be also performed for user defined relations.
The objective function has the following general form:

\[
\sum_{t} \left[ \beta_{m}^{t} \Delta t \left( \sum_{svd} \sum_{l} z_{svd..lt} \epsilon_{svd} \left[ c_{cur}(svd, t) + \sum_{i} \sum_{m} r_{svd\ m}^{l} \epsilon_{i} \right] 
+ \sum_{svd} \sum_{e=0}^{e_{d}} U_{svd e t} \epsilon_{svd} \left[ c_{cur}(svd, t) + \sum_{m} r_{svd\ m}^{l} \epsilon_{i} \right] 
+ \sum_{m} r_{svd\ m}^{l} \epsilon_{i} \right] 
+ \beta_{b}^{t} \epsilon_{t d} \left( \sum_{svd} \sum_{t=\tau}^{t+t d} \Delta(t - 1) \right) Y_{svd..t} \right] 
\left[ c_{cap}(svd, t) \left( \sum_{i} r_{svd n}^{m} m_{n} \sum_{m} r_{svd\ m}^{l} \epsilon_{i} \right) \right] \]

where

\( \Delta t \) is the length of period \( t \) in years,

\( \beta_{b}^{t} = \prod_{i=1}^{t-1} \left( \frac{1}{1 + \frac{dr(i)}{100}} \right)^{\Delta i} \),

\( \beta_{m}^{t} = \beta_{b}^{t} \left( \frac{1}{1 + \frac{dr(t)}{100}} \right)^{\Delta t} \),

\( svd \) identifies the conversion technology, such that \( s \) identifies the main energy input of the technology, \( v \) is additional identifier of the conversion technology, \( d \) identifies of the main energy output,

\( z \) identifies the level on that the main energy output of the technology is defined,

\( dr(i) \) is the discount rate in period \( i \) in percent,

\( z_{svd..lt} \) is the annual consumption of technology \( v \) of fuel \( s \) load region \( l \) and period \( t \); if \( v \) has no load region, \( l = \ldots \),

\( \epsilon_{svd} \) is the efficiency of technology \( v \) in converting \( s \) to \( d \),

\( c_{cur}(svd, t) \) are the variable operation and maintenance costs of technology \( v \) (per unit of main output) in period \( t \),
\( r_{omt}^{svd} \) is the relative factor per unit of output technology \( v \) for relation constraint \( m \) in period \( t \), load region \( l \),

\( car1(m,t) \) and \( car2(m,t) \) are the coefficients for the objective function, that are related to the user defined relation \( m \) in period \( t \),

\( car1(ml,t) \) and \( car2(ml,t) \) are the same for load region \( l \), if relation \( m \) has load regions,

\( U_{svd.e.t} \) is the annual consumption on fuel \( s \) of end-use technology \( v \) in period \( t \) and elasticity class \( e \),

\( r_{omt}^{svd} \) is the relative factor per unit of output technology \( v \) for relation constraint \( m \) in period \( t \),

\( cred(d,e) \) is the cost associated with reducing the demand for \( d \) to elasticity level \( e \),

\( Y_{svd..\tau} \) is the annual new built capacity of technology of technology \( v \) in period \( \tau \),

\( cf_{fix}(svd,\tau) \) are fix cost operation and maintenance cost of technology \( v \) that was built in period \( \tau \),

\( cc_{ap}(svd,t) \) is the specific investment cost of technology \( v \) in period \( t \) (given per unit of main output),

\( fr_{in}^{svd} \) is the share of this investment that has to be paid \( n \) periods before the first year of operation,

\( rc_{omt}^{svd} \) is the relative factor per unit of new built capacity of technology \( v \) for user defined relation \( m \) in period \( t \),

\( fr_{a}^{n,svd,m} \) is the share of the relative amount of the user defined relation \( m \) that occurs \( n \) periods before the first year of operation (this can, e.g., be used to account for the use of steel in the construction of solar towers over the time of construction),

\( R_{zr}	ext{gpl.}lt \) is the annual consumption of resource \( r \), grade \( g \), elasticity class \( p \) in load region \( l \) and period \( t \),

\( c_{res}(rgpl,t) \) is the cost of extracting resource \( r \), grade \( g \), elasticity class \( p \) in load region \( l \) and period \( t \) (this should only be given, if extraction is not modelled explicitly),

\( l_{zrcp.}lt \) is the annual import of fuel \( r \) from country \( c \) in load region \( l \), period \( t \) and elasticity class \( p \); if \( r \) has no load regions \( l = "." \),

\( c_{imp}(rcpl.\ t) \) is the cost of importing \( r \) in period \( t \) from country \( c \) in load region \( l \), and elasticity class \( p \),
$Ezrcp. \, lt$ is the annual export of fuel $r$ to country $c$ in load region $l$, period $t$ and
elasticity class $p$; if $r$ has no load regions $l = \cdot \cdot$, and

$cexp(ecpl,t)$ is the gain for exporting $r$ in period $t$ to country $c$ in load region $l$, and
elasticity class $p$.

- **The Time Horizon – Discounting the Costs**

The whole time horizon of the calculations is divided into periods of optional length. All
variables of MESSAGE are represented as average over the period they represent, resulting in
a step-function. All entries in the objective function are discounted from the middle of the
period to the first year, if they relate to energy flow variables and from the beginning of that
period if they represent power variables. The function to discount the costs has the following
form:

$$c_t = \frac{c^r}{\prod_{k=1}^{t-1}(1 + \frac{dr_k \Delta t}{100}) f_i},$$

where

$C^r_t$ is the cost figure to be discounted,

$c_t$ is the objective function coefficient in period $t$,

$$f_i = \begin{cases} 1 & \text{for costs connected to investments}, \\ \left(1 + \frac{dr_k}{100}\right)^{\frac{\Delta t}{2}} & \text{else, and} \end{cases}$$

$dr_k$ is the discount rate in period $k$. 