BRUS2 an energy system simulator for long-term planning

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BRUS2 is a technical-economic bottom-up scenario model. The objective of BRUS2 is to provide decision-makers with information on consequences of given trends of parameters of society like population growth and productivity, and of political goals, *e.g.*, energy saving initiatives. BRUS2 simulates the energy system by four demand sectors: residential, service, production, and transport, and by two supply systems: electricity, and gas and oil. The simulations are carried out in three years: a base year for calibration, a midterm year preferably in accordance with the planning horizon of national and regional plans, and an end year, used to study long-term trends of development of society and technology. The results of simulations include fuel demand, emissions of pollutants, and economic consequences. BRUS2 has been implemented in several countries, recently in Mexico. The methodology is described and illustrated with some examples.

Keywords: Energy simulators; energy saving

El BRUS2 es un modelo integral para escenarios técnico-económicos. El objeto de BRUS2 es proveer de tomadores de decisión con información sobre las consecuencias de tendencias de parámetros sociales como el crecimiento de población y productividad y de metas políticas, por ejemplo, iniciatives para el ahorro de energía. El BRUS2 simula el sistema energético por cuatro sectores de demanda: residencial, servicios, producción y transporte, y por dos fuentes de producción: electricidad y gas y petróleo. Las simulaciones se realizan en tres años: un primer año para calibración, un año intermedio preferentemente de acuerdo con el horizonte de planeación nacional y planes regionales y un tercer año que se usa para estudiar las tendencias a largo plazo del desarrollo en la sociedad y la tecnología. Los resultados de las simulaciones incluyen la demanda de combustibles, emisión de contaminantes y consecuencias económicas. El BRUS2 ha sido implementado en varios paises y recientemente en México. La metodología se describe e ilustra con algunos ejemplos.

Descriptores: Simuladores de energía; ahorro de energía

PACS: 89.30.+f; 89.40.+k; 89.50.+r; 89.60.+x

1. Introduction

BRUS2 is a long-term scenario model that simulates the energy aspects of society comprising demand, conversion, and supply of energy, and estimates consequences concerning energetic, economic, and environmental aspects. It applies a bottom-up methodology and calculates energy consumption, emissions, and related energy systems costs including investments, operation, and maintenance costs in addition to fuel costs. The model facilitates long-term analyses and has explicitly incorporated important long-term factors of the energy system, *e.g.* development of energy technologies and conservation.

The model contains a fully specified energy system, describing the most energy consuming sectors of society and their aspects of technical, demographic, economic, and environmental nature. BRUS2 has its origin in a model developed and used for the Danish energy planning. This model is suited to be adapted to conditions in countries or regions to which it is transferred, *e.g.*, the description of the oil-sector may be enlarged, and the number of pollutants increased.

The model is based on the Excel spread sheet system, and includes visual basic; the system consists of approximately thirty sheets and a number of macros.

This paper describes the background for the work, the general concept of the model, some details, and finally, its use is illustrated with a few examples.

2. Objective

The objective of BRUS2 is to provide decision makers with information of consequences of decisions taken today that influences the society in the coming years, *e.g.* as needed for national energy planning. Thus, estimates of the evolution of the population and of production factors together with political initiatives to change energy demand and supply are assumptions for the model, which calculates consequences concerning fuel consumption and of economic and environmental aspects. In this way, BRUS2 supports national or international studies and policy making aimed at attaining a sustainable future.

3. Institutional background

BRUS2 is developed at Risø National Laboratory, which is a Danish institution under the Ministry of Research and Information Technology. It carries out research in science and technology, providing Danish society with new opportunities for technological development.

Risø was established around 1955 with emphasis on research related to energy aspects, among which were nuclear physics and technology.

In Denmark there is a long tradition for energy planning that was accentuated during the oil crisis in the 70's due to a nearly total dependence on imported fuels (presently, most domestic oil and gas demands are supplied from national fields in the North Sea). During these years, Risoe National Laboratory initiated work within this field: a number of specialists, comprising technicians and economists, formed the Energy Systems Group, concentrating on energy related subjects like planning, security of supply, and associated economic aspects. The group assisted the ministry of Energy in formulating energy plans and carried out the overall simulation of the energy system. As part of this task, one of the first efforts was the development of a comprehensive model of the Danish energy system called DES (Danish Energy System).

This activity is still continued, the model (later redesigned and renamed to BRUS—Brundtland Scenario model) being modified to serve actual needs of the current Danish energy plan. Through international co-operation, the methodology has been implemented in countries in Europe, Africa, and America, the model being adapted to the actual energy system and available statistical data. Presently, as part of a World Bank financed study of the Mexican energy system and its environmental aspects, BRUS2 is being modified and adapted to Mexico.

4. General features of the BRUS2 model

BRUS2 is a technical-economic model with an integrated treatment of energy demand and supply, which allows for the calculation of demand-driven scenarios of the total energy system. The main purpose of the model is to analyse cost-effective and sustainable strategies for the reduction of greenhouse gases and harmful emissions. Simultaneously, potential minimisation of demand for exhaustible resources is analysed.

The main features of the model are:

- A long-term simulation model which projects to *e.g.*, year 2030, but only calculates three years a base year, a mid-term year, and the long-term year.
- The model is comprehensive (in contrast to partial or marginal models), making it possible to introduce significant changes *e.g.* on the demand side, and nevertheless get reliable results for the total energy system.
- It is subdivided into different sectors of energy demand and supply, which are integrated to provide a useful and comprehensive tool. Thus, it is possible in the model to evaluate demand side changes compared to supply side changes that concerns the consequences for energy, environment, and costs.
- Macroeconomic driving parameters for energy demand are directly incorporated in the model, *e.g.* industrial production as activity parameter for energy consumption by industry.
- Energy demand and the development of energy production capacity are driven from the demand side.
- It is possible to choose various saving options for domestic consumption, electrical appliances, and industrial processes.
- It is possible to configure the future energy system by choosing from a large number of energy conversion technologies.

The model simulates the society such that demands for energy are calculated and the corresponding supply in selected years and estimates consequences of economic and environmental nature.

The society is represented such that its energy demand may be simulated in detail according to available statistics (and data that may be obtained in near future). Therefore, the demand is split into sectors, which are characterised by a uniform type of energy consumption; BRUS2 has four demand sectors: residential (households), service, production, and transport, each with a demand depending on its characteristics.

The total demand for energy from these sectors is satisfied by certain supply systems: power supply, oil, and gas supply.

Generally, BRUS2 is a point model, all data being without reference to a particular geographical region; however, in the case of Mexico, the power sector is split into three major regions due to technical reasons.

The scenario years may be chosen like this:

- Base year for calibration with statistics.
- Midterm year inside the range of most important national and regional plans, *e.g.*, Base year + 10.
- Long-term year that permits "free/unbiased" experiments with parameters, *e.g.*, Base year + 20–30.

It is important that although not every year is represented, a technical and economic path can be sketched, along which society may evolve between these scenario years.

Thus, it is seen that the model contains data derived exogenously from statistical data—for the base year, and data calculated endogenously that depends on the selected scenario parameters—for mid-term and end-term years.

BRUS2 generates results concerning

- Power and fuel consumption by type and sector, *e.g.*, coal, fuel oil, renewable.
- Emissions by sector, technology, and type, *e.g.*, CO_2, SO_2, NO_x.
- Power production by plant type, *e.g.*, base load plants, wind turbines, etc.

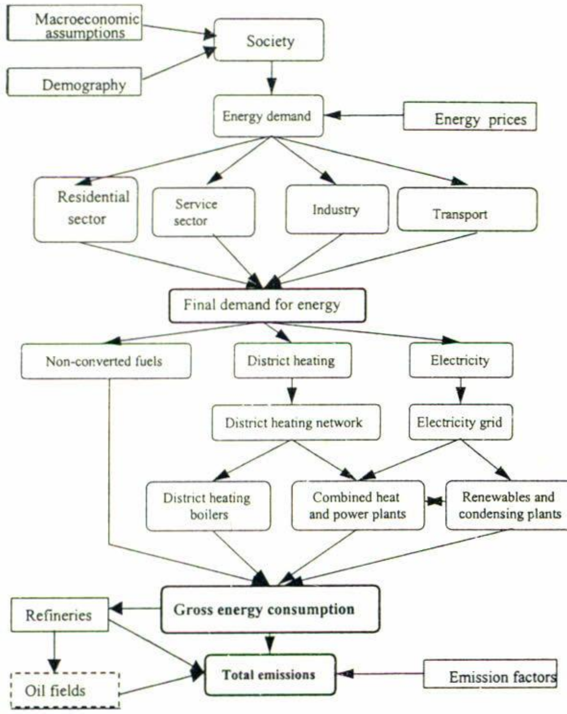

FIGURE 1. Diagram of BRUS2.

- Operation and maintenance costs by technology, *e.g.*, fuel and O & M cost.
- Levelised investments, *e.g.*, in saving and substitution options.

An outline of the dataflow in the model is given in Fig. 1. In the following sections, details of BRUS2 are given.

4.1. Demand side

The description of the demand side must correspond to the format of the national statistics; it is split into four main sectors, namely

- Residential sector with households.
- Service sector with private and public enterprises and institutions.
- Production sector including the various raw material exploration and manufacturing enterprises.
- Transport sector comprising various types of public and private transport means of passengers and goods.

The driving factor for net energy demand depends on the particular sector and includes

- Gross Domestic Product (GDP).
- Population.
- Energy prices.

The detail, in which the sectors are described, reflects a compromise between available statistics and the need to obtain data necessary to predict the dependence of essential variables on scenario parameters.

The residential sector is described according to available statistics, *e.g.*, number of households split into urban and rural, each characterised by their specific use of energy for cooking and hot tap water, and possible heating/cooling demand.

In addition, a number of electrical appliances, common in households, may be used to specify additional electricity demand in this sector; the list contains electrical devices like micro ovens, TV sets, refrigerators, washing machines, etc., each with a specific yearly consumption; the number of appliances in use is specified by a coverage percentage.

The service sector is primarily split in two subsectors:

- public service with activities like administration, health, education, together with road lighting, water supply, and sewage draining systems.
- private service with activities like restaurant, hotels, commerce, banks, etc.

These sectors' demand is mainly electricity and energy for heating/cooling.

The production sector comprises the following main activities

- Mining and oil/gas activities.
- Heavy industries.
- Light industries.
- Food and beverages.
- Agriculture.

The list reflects the most energy consuming branches of industry as described in national statistics.

The transport sector is split in demand for private and public passenger transport, and in goods transport. For each type, the transport is split in various transport means: *e.g.*, for passengers:

- Cars.
- Busses.
- Trains.
- Air transport.
- Sea transport.

Each is further split in actual fuels (gasoline, diesel, etc.).

Detailed information on transport is often sparse, the sold fuel and the number of vehicles being the available data. However, as transport's energy demand is large and its contribution to emissions, especially the local, significant, it is instead of urgent read important, to obtain data in order to estimate the influence from this sector.

4.2. Supply side

The energy supply side contains two major systems, some are connected with consumers through lines and pipes:

- Oil and gas sector.
- Power sector.

that will be described in some detail in the following.

4.2.1. Oil and gas sector

The simulation of this sector describes the balance between crude oil and gas production at the well heads and the sum of demand and export/import; further, emissions of greenhouse gases are estimated due to flaring and venting, to production losses, and to consumption for running the processes. Further, some economic costs of the operation and maintenance are estimated.

The oil and gas supply sector comprises

- Oil and gas wells.
- Refineries.
- Gas plants.

BRUS2 simulates very simplified the flow of hydro carbons from well heads till the consumer; it takes into account various crude qualities, flaring and venting at the well heads, the split of crude to the refineries, auto-consumption, and losses.

4.2.2. Power sector

This sub-model is intended to simulate the operation of the electricity supply system with the aim to satisfy the demand and thereby estimate the fuel demand, emissions, and costs, including investments in new power plants.

The model of this sector is—due to its magnitude and complex operation— simplified but fuel consumption, emissions, and costs are—depending on available data—estimated with reasonable accuracy.

The power sector comprises in principle all existing and planned power plants and international transmission lines. Typical plant types represented:

Renewable energy sources like:

- Hydroelectric.
- Geothermal.
- Wind power.
- Solar.
- Wave.

Convention plants as:

- Steam cycle.
- Gas turbines.
- Combined heat and power plants.
- Emergency plants.

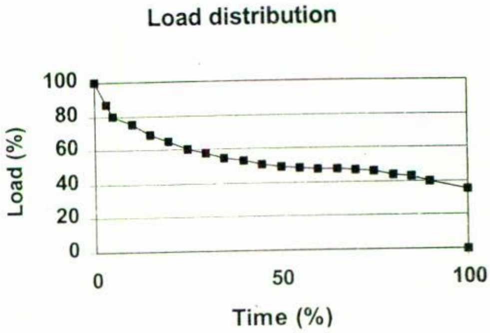

FIGURE 2. A typical load duration curve.

The power system may be split into regional subsystems. Losses in the transmission and distribution system may be taken into account.

Each power plant is characterised by a start year and a life time (in this sense, the power sector is more detailed than the other parts of the model, as each year between the base year and the long-term year is represented in order to take into account the large investments in power plants). Further, each power plant is characterised by a number of parameters, *e.g.*:

- Installed capacity.
- Efficiency.
- For co-producing plants, the ratio between power and heat.
- Fuel mixture, *e.g.*, 50% fuel oil and 50% natural gas.
- Investment.
- O & M costs, fixed and variable.

The production of a plant is given by its capacity and the number of equivalent full power hours; the latter may be obtained from *e.g.*, a load dispatch model or by extrapolating existing statistics. If no data are available, they may be generated in BRUS2 with a very simple load dispatch model, based on a sorted representation of the time dependent electrical load as seen in Fig. 2. To run this, each plant is provided (by the user) with an availability (that fraction of the year, in which the plant is available for power production) and a priority (giving the sequence in which the plants are "put into operation" by the load scheduler, *i.e.*, first base load plants—efficient units with low fuel costs, next medium load—*e.g.*, simpler and therefore cheaper technology, but with higher fuel costs, or older units, and finally, the peak load plants—running few hours per year). The load dispatch routine puts the units into the load duration curve, calculates the number of full power hours, from which fuel demands, emissions, and costs are derived.

4.3. Emissions

The emission of various chemical compounds due to energy exploration, conversion, transmission, and consumption is an important issue because many of these compounds are characterised either as green house gases or as toxic to the biosphere. Emissions are generated in the demand as well as the supply sector. Therefore, BRUS2 estimates the emissions within the frame of the model.In principle, emissions may be grouped in

- Airborne emissions.
- Emissions contained in sewage water.
- Waste to the soil.

Although as seen from a total environmental point of view, all three are very important, the airborne emissions are in focus in the present version of BRUS2, as the energy consumption will mainly result in this form of emissions; in addition, the other forms are more complicated to handle.

The estimate of the emissions due to use of energy is based on a set of specific emission factors depending on

- Fuel type.
- Combustion process.
- Technology.

Thus, emission factors are specific to *e.g.*,

- Power sector—each plant and fuel type.
- Oil and gas sector—each refinery and gas plant.
- Transport sector—each transport mode and fuel type.

Examples of emissions that are estimated:

- CO_2
- SO_2
- NO_x
- CH_4

Other compounds may be of equal importance, *e.g.*, originating from the transport sector:

- VOC's.
- Dust.

However, due to the present lack of data not all are included. The quantification of the emissions follows the principles below:

CO_2 It is simplifying assumed that all combustion of carbon compounds is complete, so the amount of CO_2 corresponds to the contents of carbon in the fuel. In addition, CO_2 is part of the gases vented from certain wells.

SO_2 The same procedure used for CO_2 is assumed valid for the sulphur contents of fuels. However, if a desox flue-gas cleaning system is installed, *e.g.* in power plants, the emission has to be corrected accordingly.

NO_x The NO_x emissions among other depend on the temperature during combustion, and thus of the technology used; therefore a particular coefficient is assigned to different processes (fuel oil burners, diesel motors, etc.). Like for SO_2 emissions, a denox cleaning system may be in use (catalysts on cars), and if so, the emission must be corrected accordingly.

CH_4 Methane is transported through a large pipe and gas handling system; emissions are due to leaks and process losses.

4.4. Economic factors

In order to estimate economic consequences of supplying the society with energy, and at the same time implementing saving initiatives and substitutions, a number of economic data is needed.

BRUS2 includes economic variables like:

- Fuel prices.
- Operation and maintenance costs.
- Investments.
- Production values (GDP).
- Saving cost functions.
- Substitution costs.

These data should be in accordance with national and regional economic planning studies or obtained from dedicated studies of particular technologies, or from international studies, where relevant.

These data are important in the scenario runs, being parameters that are varied in order to test the robustness of a particular solution.

5. Scenario runs

BRUS2 being a scenario model calculates—in the two scenario years—the consequences of specified scenario assumptions. The model is constructed to facilitate the development of scenarios. Given a baseline, scenarios are developed using a number of choice-parameters, which includes:

- Choices at the society level, *e.g.* the macroeconomic growth and the development of energy prices.
- The long-term structure of the energy system, *e.g.* a future system based on a continued utilisation of a centralised systems or more decentralised solutions.
- Choices of options reducing or changing the energy demand, *e.g.* the degree of realising insulation potentials.
- Choice of technology and fuel substitution at the local, decentralised and centralised supply level.

Choices of the above-mentioned parameters define a scenario in BRUS.

Usually, a base scenario is constructed without any savings or substitutions, and this is used as reference for runs with particular substitutions and savings, from which key figures may be found, *e.g.*, the cost to decrease the CO_2 emissions a given percentage.

The main results of the model are summarised below:

- Total gross energy consumption, subdivided into sectors and types of energy.

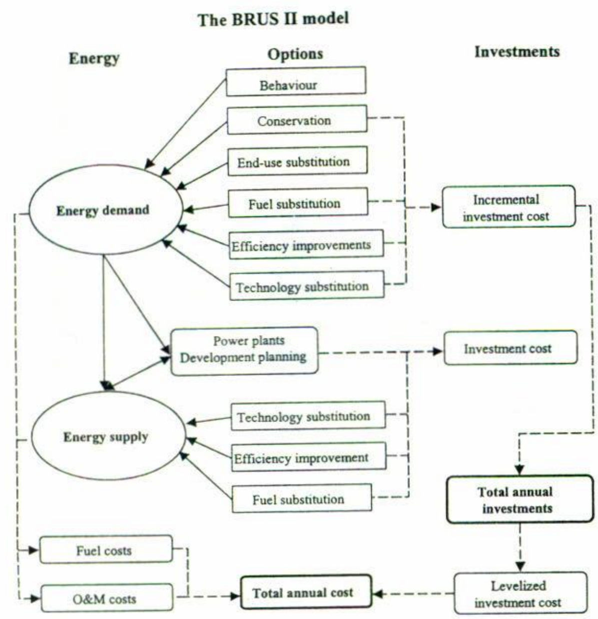

Figure 2 Options of BRUS2

FIGURE 3. Options of BRUS2.

- The energy related emissions.
- The annual systems cost, including levelised investment costs, operation and maintenance costs and fuel costs.
- Total capacity development and the related investment costs on an annual basis.

5.1. Substitutions and saving options

An important feature of the model is the options to study consequences of introducing substitutions and initiating savings. At supply level the substitutions may concern technology and fuel, and at consumer level, the options comprise substitutions, saving measures, and changes of user behavior. In all cases, in addition to the (decreased) fuel demand, the running costs and investments are estimated.

BRUS2 contains a large number of substitutions, in practice only the available information sets the limits. In Fig. 3 an outline of the options is given.

The substitutions will—normally—decrease the business-as-usual energy demand that for a particular energy service is determined by an appropriate formula, based on regression analyses of historical data, where the variables may be the production value, the energy price, and the population, the actual form depending on the sector regarded.

In the following, a few examples are outlined.

5.1.1. Substitutions

An example of technology substitution is a change of a particular electrical appliance with another brand or type with better efficiency (*e.g.*, fluorescent lamps in stead of incandescent bulbs); another example is substitution of one fuel type with another, which may result in less pollution (*e.g.*, use of biomass or natural gas in stead of fuel oil).

5.1.2. Saving options

In order to study consequences of energy saving incentives, BRUS2 is provided with options for specification of a percentage saving of the net demand obtained by introducing technology improvements or changes. The investments coupled to these saving options are estimated by means of a regression formula, obtained by means of auxiliary studies of potential saving technologies and their costs, which, of course, depends on the local technology.

5.2. Public behavior

Through education, advertisements, and other initiatives it is—to a certain extend—possible to increase the awareness of benefits of saving energy and therefore modify the behaviour and habits of the "common" consumer. As an example a TV-spot may persuade pendlers to join into car-pools or to use public transport. The behaviour is specified as an index in the relevant sector. If experiences give some quantitative estimates of possible savings, they may be specified in BRUS2.

Savings in this sense do not imply any costs.

6. Sources of information and interaction with other models

BRUS2 is not a stand-alone model but needs input of statistical nature and should take into account other studies in order to agree with assumptions in national and regional planning and political goals.

In addition to the power production data mentioned above, some basal data are:

- Expectation of demographic data including growth of population.
- Goals concerning gross national product and fuel prices.
- Plans for the future power system.
- Estimations of exploitation of oil and gas fields.

An interesting issue is the interplay between national macroeconomic models and BRUS2: In many cases, the macroeconomic model does not focus on energy supply and demand in detail with options as provided by BRUS2; therefore scenario results or may be fed back to the macroeconomic model, which in turn provides new energy prices and productions, etc., which are input to BRUS2.

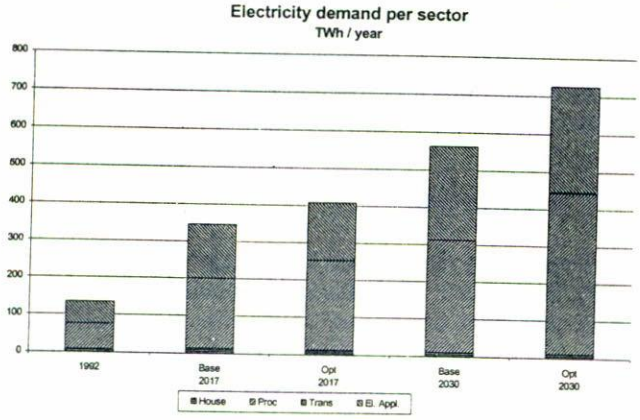

FIGURE 4. An example of a case study with BRUS2: Electricity demand in a base case and in an optimistic case with higher GDP growth.

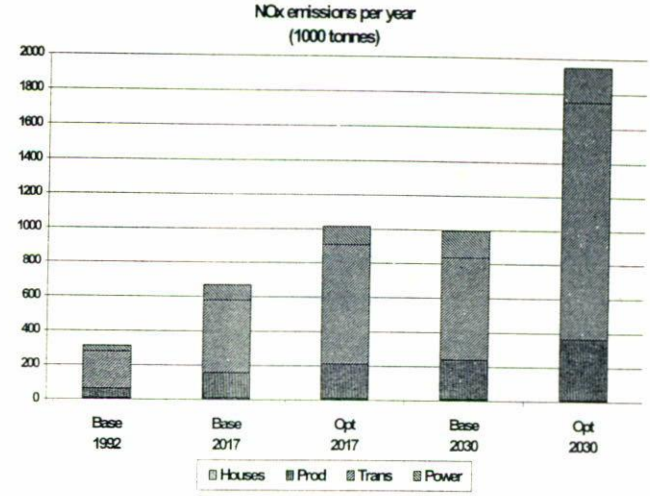

FIGURE 5. A case study with BRUS2: NO_x-emissions per sector in a base case and in a case with higher GDP-growth.

7. Case studies

In the following, the use of BRUS2 is illustrated by some typical examples obtained from scenario runs. The figures shown depend on actual data and should be taken as illustrations only [The data does not refer to Mexico!].Usually, two cases are studied:

- Business as usual with GDP growth according to national planning.
- Optimistic expectations to the future development expressed through a higher GDP growth.

In Fig. 4 the electricity demand is shown for the two cases represented by a 1.7% yearly increase of the GDP—the base case, and optimistic with a 1.9% yearly growth.

In Fig. 5 the resulting NO_x emissions are shown, where no special action has been taken to introduce NO_x abatement techniques. This will, of course, be the next step in the study.

On "top" of these scenarios, various saving and substitution strategies may be introduced and tested, *e.g.*, in order to decrease the NO_x-emissions, and finally, the specific costs of emission reductions may be calculated and compared with other options.

8. Conclusion

BRUS2 is a bottom-up model simulating energy aspects of society, estimating environmental and economic consequences. A scenario technique is used and the calculation presumes that future data concerning demography, GDP, and fuel prices are supplied exogenously, *e.g.*, by macroeconomic models and other studies.

Experience shows that although originally designed for north European energy systems, the concept is very flexible and BRUS2 has been adapted successfully to other countries.

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