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ESTIMATING THE CONSEQUENCE OF INTRODUCING WIND ENERGY AND BIOMASS ENERGY TO THE ENERGY SECTOR[*]

WIESŁAW CIECHANOWICZ
ELŻBIETA MARCINIAK
SYSTEMS RESEARCH INSTITUTE,
POLISH ACADEMY OF SCIENCES,
Newelska 6
01-447 Warsaw,Poland

Abstract:
A preliminary estimation of the consequences of introducing wind energy and biomass energy to the energy sector is conside - red in order to evaluate the scale of the problem. The selected technologies are intended to be applied in the scenario evaluations of energy sector expansion by use of a computer system for estimating the consequences of introducing the technology innovation to the economy.

Keywords: energy, national economy, natural environment.

1. Introduction

In paper: Ciechanowicz, Łabuda /1987/, selected future economic situations of the Polish economy have been considered assuming that suitable action had been undertaken in order to

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weaken the hypothetic energy deficit. One of the remarks of this paper was the following: "in the case of significant nuclear fuel price increase as well as nuclear reactor technology cost increase the substancial expansion of nuclear power plants cannot be a solution of decreasing the expected fuel deficit. To decrease in the future expected fuel import the potential candidates could turn out among others to be wind energy and biomass energy".

The aim of this paper is the preliminary consequence estimation of introducing wind energy and biomass energy to the energy sector in order to evaluate the scale of the problem. The technologies are viewed both separately as well as in suitable hybrid systems. The aim is also the preliminary selection of adequate technologies from the admissible set of technologies. The selected technologies are intended to be applied in the scenario evaluations of energy sector expansion by use of a computer system for the consequence estimation of introducing the technology innovation to the economy.

To estimate the economic consequences we evaluate: 1. total utilization cost, 2. financial expenditure return functional and 3. coefficient of financial expenditure return.

Total utilization cost, TUC, is determined as the sum of:

- specific investment cost, SIC,
- annual fixed operating cost, AFOC,
- variable operating cost, VOC,
- unit fuel cost, FC, equal to $1/\eta \cdot c$, where η -efficiency, c - fuel price,
- social costs denoted by SC.

The return functional of financial expensiture is used as a selection measure of the technology competition between two chosen competing technologies and is of the form:

$$R(T) = \int_{0}^{T_1} g(t)\, dt + \int_{T_1}^{T} g(t)\, dt$$

where $g(t)$ is the return gain defined as

$$g(t) = \Delta SIC(t) + \Delta AFOC(t) + \Delta VOC(t) + \Delta FC(t) + \Delta SC(t)$$

and Δ - the difference of suitable costs for two competing technologies.

It is assumed that the technology capacities will be installed only within time interval $[0, T_1]$.

We define the coefficient of financial expenditure return as the ratio of the return functional, to be considered as the total reference gain within time interval $[0,T]$, to the total investment expenditures to be provided within time interval $[0,T_1]$, namely

$$CR(T) = \frac{R(T)}{\int_{0}^{T_1} SIC_i^{i}(t)\, dt}$$

where index i involves the considered technology to be installed.

In all calculations of the coefficient of financial expenditure return we assume that the technology capacities will be installed within the first 20 years of the considered overall time interval equal to 40 years, A ten year investment cycle is assumed. CR(T) will be determined only in the time interval [20, 40 years].

We will make the assumptions that:

- for wind energy conversion system, WECS, the capacity factor is assumed to be equal to:
  onshore wind conditions - $CF_w = 0.25$ and $CF_w = 0.33$,
  offshore wind conditions - $CF_w = 1.6 \times 0.33$ and $CF_w = 2 \times 0.33$,
- SIC and AFOC for WECS offshore conditions will constitute additionally 68% of WECS onshore conditions Hardell, Werner /1981/,

In our considerations mainly plantations of wood, as a biomass, are assumed to be utilized and short rotation intensive culture /SRIC/ of forestry to produce wood energy feedstocks is assumed to be applied Perlak, Warren /1987/. SRIC is a silvicultural system that utilizes fast-growing wood trees, rotations or cutting cycles of 3-10 yr. densely spaced trees, weed control, fertilization and other agronomic inputs.

The economic and technical data given mainly in Perlak i Warren /1987/, Julich /1982/, Avery i in. /1985/, Morgan i in. /1973/, wegian WTS-3 : Julich /1982/. The base coal price is equal to $c(t) = c_o \cdot (1 + b \cdot t)$, where $c_o = 2.32$ \$/GJ and coal price increase b= 4% per year. The base cost of SRIC wood feedstock is assumed to be 2 \$/GJ according to Perlak, Warren /1987/.

2. Considered technology set

The economical aspects are investigated for single technologies such as:

- wind energy form localized onshore and offshore competing with coal fired power plant,

- medium CV wood gasification technology competing with medium CV coal gasification technology,
- wood to ethanol bioconversion technology competing with coal to methanol chemical conversion technology,
- anaerobic digestion technology of wood competing with medium CV wood gasification technology.

The hybrid systems, in which wind or biomass energy participates, are the subject of investigations like:

- hybrid system: photovoltaic power system - wind energy - battery storage competing with coal fired power plant,
- ammonia production hybrid system: wind energy farm - hydrogen storage- ammonia synthesis competing with the ammonia market price,
- methanol production hybrid system: wind energy farm - gasification of biomass - hydrogen storage - methanol synthesis competing with the methanol production technology based upon wood gasification and methanol synthesis.

The integration of PV power system, WECS and battery storage will enable the supply of electricity for residential use in remote and rural areas as well as in coastline areas where the proper wind conditions exist. We assume that:

- capacity factor for PV power system is equal to $CF_{PV} = 0.16$ as an average value of CF = 0.12 for Norwegian weather conditions and CF = 0.2 for Italian conditions,
- for 6 hours of battery storage $CF_B = 0.25 \times CF_{PV}$,
- according to Julich /1982/ specific investment cost of PV power plant will decrease from the value of 841 $/kW for

2000 y to 682 $/kW for 2020 y.

The ammonia production hybrid system can possess great potential in the future in order to substitute:

- natural gas as a source of hydrogen for ammonia manufacture,
- in some extent fossil fuel for vehicle or industrial uses.

The feature of this system is the possibility of wind energy storage throughout the water electrolysis process to produce hydrogen and then to produce ammonia to store hydrogern. Ammonia is the only common noncarbon fuel that can be conventionally stored as a liquid at room temperature. The wind energy farm is thought to be licalized offshore because the water electrolysis process requires large amounts of water. Therefore the water desalination process is included in the set of hybrid system technologies. Simultaneously the offshore localization of a WECS farm will enable more energy to be produced using the same number of WECS units in comparision with the onshore localization since the offshore wind speed is usually greater than onshore wind speed.

3. Preliminary consequence estimation

From the considered technology set we distinguish the following technologies which could be applied in order to decrease the expected energy deficit in the future, namely:

- wind energy farm,
- medium CV wood gasification,
- hybrid system: photovoltaic power system - wind energy farm -

battery storage,

- ammonia production hybrid system: wind energy farm localized offshore - water electrolysis - hydrogen liquefraction and storage - ammonia synthesis.

The first priority would be given to the technologies:

- ammonia production hybrid system,
- medium CV wood gasification,
- wood to ethanol bioconversion.

On the basis of the data given in Julich /1982/, Avery i in. /1985/, the estimated cost of ammonia produced by a hybrid system utilizing wind energy is equal to 370 $\$/t_{NH_3}$ by assuming that the capacity factor for hydrogen storage $CF_H = 0.322$ and $CF_w=1.6x0.33$. If the real price of oil increases at 1 to 2% per year, natural gas cost $ 0.19 - 0.22 m^3 in 1990 and the ammonia market price would reach 275-300 $/t/ $ 1983/. At this value, the estimated cost of ammonia, when wind energy is utilized , would be sufficiently attractive after the year 2000 to warrant significant interest in the development of the considered hybrid system. For a time horizon of 40 years the coefficient of financial expenditure return, CR, reaches values of 0.633 and 2.86 for constant and increasing ammonia market prices,respectively. That means that one $ of financial expenditure to be paid for investment in the energy sector would bring a gain of the order from 0.633 to 2.86 $ depending upon the ammonia market price increase if we invest it into the ammonia production hybrid system.

For the medium CV wood gasification technology for the time horizon of 40 years ,the coefficient CR can range from the value of 2.55 , for constant coal price and when social costs are not included, to the value of 14.6 for coal prices increasing at 4% per year and when social costs are included.

Ethanol from wood, by use of bioconversion technology, can be produced by plants smaller than those required for economic production of methanol from coal. Therefore, it is capable of being implemented comaratively rapidly and avoids the lead times and investment problems associated with large scale synthetic fuel plants. For the 40 year time horizon the coefficient CR for wood to ethanol bioconversion reaches values of 1.16 and 10.57 for constant and increasing coal price, respectively when it competes with coal to methanol chemical conversion. Also the production of ethanol from municipal solid wastes seems to be attractive.

The preliminary consequence estimation of introducing the above mentioned technologies to the energy sector leads to the conclusion that there could be:

- the possibility of substitution of natural gas at the amount of $2.18\ 10^9\ m^3$ / to be equivalent to $2.9\ 10^6$ tons of coal/ if $2\ 10^6$ tons of ammonia production per year is predicted by utilizaton of wind energy,
- the possibility of biomass utilization equivalent to $18 \div 25 \cdot 10^6$ tons of coal equivalent per year to produce medium CV gas or ethanol.

The second priority would be given to the PV solar -wind energy hybrid system.

The total utilization costs /TUC/ for a PV solar -wind energy hybrid system and coal fired power plant have been evaluated by an additional assumption that:

- the capacity factor for a PV power system is equal to $CF_{PV}=0.16$ as an average of CF = 0.12 for Norwegian weather conditions and CF = 0.2 for Italian weather conditions,
- for 6 hours battery storage $CF_B = 0.25 \times CF_{PV}$.

The results are the following:

1. for a coal fired power plant:

   $TUC = 12.6$ $/$GJ_e$ for $c_c = 2.32$ $/GJ,

   $TUC = 19.4$ $/$GJ_e$ for $c_c = 2 \times 2.32$ $/GJ,

2. for a PV solar - wind energy hybrid system:

   - onshore wind conditions $CF_w = 0.33$

     $TUC = 14.9$ $/$GJ_e$ for year 2000,

     $TUC = 13.9$ $/$GJ_e$ for year 2020 ,

   - offshore wind conditions $CF_w = 1.6 \times 0.33$

     $TUC = 10.4$ $/$GJ_e$ for year 2000,

     $TUC = 9.7$ $/$GJ_e$ for year 2020.

For the time horizon 40 years, coefficient CR reaches values in the range of 0.465 - 1.244 for constant coal price and in the range of 2.15 - 3.4 for increasing coal price /at a rate 4% per year/ for the considered values of WECS capacity factors. Moreover , the considered hybrid system could substitute from $1.42 \cdot 10^6$ tons of coal for onshore wind conditions

with $CF_w = 0.25$

to $2.58 \; 10^6$ tons of coal for offshore wind conditions.

with $CF_w = 2 \times 0.33$

per 1000 MW of installed power of a coal fired power plant.

Wind energy technology being no more complec than automobiles to produce , as well as wood gasification technologies can be manufactured by Polish industry. This is the first economic consequence of applying wind energy or biomass conversion technologies. This would make it possible to decrease the import of energy device technologies what would be required if only nuclear energy is intended to be utilized to decrease the expected energy deficit.

The second economic consequence would be the possibility of decreasing nuclear fuel import if to some extent, wind energy and biomass resource nuclear energy in the future.

The third economic consequence results from the fact that most of the suggested wind energy and biomass technologies are characterized by the fact that the financial investments in then would be returned relatevely fast and would bring relatevely high profit in comparision with the considered competitors of the investigated technologies.

The fourth economic consequence has the environmental protection aspect. In contrast to conventional methods of power generation, wind energy conversion is highly favorable from the environmental standpoint, posing no major societal risks. One particular advantage is that no water is required and no air or thermal pollution is produced. The only disadvantage is the fact the wind energy resource availability is constrained.

The carbon to hydrogen ratio is smaller for biomass than for coal. Hence, in the case of biomass chemiacl conversion, less hydrogen will be required and simultaneously less CO_2 will be produced throughout the water shift reaction. Moreover, biomass plantations willc contribute to decreasing the CO_2 concentration in the atmosphere.

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