ECONOMIC-ENVIRONMENTAL APPROACHES FOR ASSESSING SUSTAINABLE IRRIGATED HOUSEHOLD FARMING SYSTEM IN COASTAL PLAIN OF BALI

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ABSTRAK

Keberlanjutan pembangunan pertanian tergantung pada pengelolaan teknologi pertanian dan intervensi pemerintah. Proyek Sustainable Development of Irrigated Agriculture in Buleleng and Karangasem (SDIABKA project) merupakan salah satu wujud pembangunan pertanian beririgasi di lahan peisir di Bali dengan dukungan investasi sistem irigasi pompa air tanah. Proyek tersebut mengembangkan 39 unit sistem usahatani campuran beririgasi yang masing-masing dikelola oleh rumahtangga tani yang tergabung dalam subak sumur pompa. Keberlanjutan sistem usahatani rumahtangga beririgasi dinilai dengan pendekatan kesepadanan teknologi irigasi yang digunakan sebagai pendukung sistem usahatani rumahtangga dan pendekatan effisiensi atau optimasi penggunaan sumberdaya pertanian secara berkelanjutan dari sudut pandang ekonomi-lingkungan.

Kata kunci: *pertanian berkelanjutan (sustainable agriculture), lahan pesisir (coastal plain), Bali, kesepadanan teknologi (appropriate technology), sistem usahatani rumahtangga (household farming system), pendekatan ekonomi lingkungan (economic-environmental approach).*

INTRODUCTION

Vision of Indonesian agri-cultural development in 2020 is to form modern and efficient agriculture which one of its charac-teristics is optimal and sustainable utilization of agricultural resources: land, water, germ plasma, labor, capital, and technology (Kasryno *et al*, 1997). Fagi *in* Sugino (2003:5) introduce two key issues for agricultural development, namely sustainability and diversity. Agricultural sustainability is determined by two important factors, i.e. technology management and government intervention. Government intervention in accordance with Sugino (2003) is made possible through heavy investment in irrigation infrastructure facilities. Irrigation in Indonesia was especially seen as a supporting factor of govern-ment policy for the success of agricultural develop-ment and self-sufficient in rice program toward self-sufficient in food as written in INPRES 3/1999. Therefore, development of irrigation facilities should be able to increase agri-cultural productivity and the income of farmers (Hernanto, 1996).

Project of "Sustainable Development of Irrigated Agriculture in Buleleng and Karangasem (SDIABKA)" that was being developed for four years (2003-2006) is an attempt to realize sustainability of agricultural resources use. The project whose its location in the eastern part of north coastal plain of Bali was being attempted (1) to install 15 groundwater irrigation system for which deep well construction were completed under "North Bali Groundwater Irrigation and Water Supply Project (NBGIWSP), ALA/91/19" (1993-1999), (2) to optimize the ground-water potential in the project area through the rehabilitation and upgrading of an additional nine groundwater irrigation systems, and (3) to develop and introduce profitable mixed-farming practices and procedures for all schemes in the project area (the 24 new system and 15 schemes developed under Project ALA/91/19 (Project Management Unit, 2003).

Coastal plain such as SDIABKA project area is generally region with poor fertile soil, high water losses through percolation and evapotranspiration, and groundwater as being the primary water source. The project area involves 12 villages (9 of which lie in Buleleng regency and 3 villages lie in Karangasem regency (Project Management Unit, 1995). Total area of them is 14.165 ha consists of agricultural land (11.513 ha), protected forest (1.572 ha), and the rest of which (1.080 ha) for other uses (BPS Kabupaten Buleleng, 2003; BPS Kabupaten Karangasem, 2003). The project area is only 5.300 ha (46 % of agricultural land), approximately 30 km long and varies in width between approximately 1 km and 3 km. The depth to the interface at 1 km from the sea is over 100 m below sea level (bsl) in all part of project area. The depth of the interface at 100 m from the sea is between 35 m and 50 m bsl. The project area is supported by catchment above the project area in amount of 18.800 ha (Project Management Unit, 1995). The catchment area might involve all of agricultural land and protected forest in which as well as part area of other villages above the project area. Project Management Unit (1995) previously predicted that total volume of groundwater flow available in SDIABKA project area is approximately 30 MCM/yr with annual recharge 7 MCM/yr. It can be depleted in the event that its abstraction is higher than its recharge. Besides that, annual recharge of groundwater in coastal plain is strongly dependent upon the stable condition of catchment area. Significanly changes (e.g. deforestation or change function of agricultural land to non agricultural uses) in catchment area will reducing annual recharge of groundwater. An experience study in India (Joshi and Tyagi, 1991) clearly demonstrated that the rate of change in production and crop yields has slowed down during the green revolution period (1972 to 1980) and post green revolution period (1980 to 1988). Reasons for those phenomena included (1) the areas endowed with good quality ground-water are being over-exploited without maintaining the water level at a reasonable depth, (2) regions with poor quality groundwater are not being extracted, therefore leading to rise in the water table. These both situations have adversely jeopardized agricultural production in the long run. These phenomena meant that as environmental degradation increases, agriculture will eventually become unsustainable (Sugino and Hutagaol, 2004). Therefore, farming system in which requires best management practices (BMPs) for farm production and appropriate technology for irrigation.

In the event that water availability is limited and competition for water among potential water users (households as well as agriculture) is high, this condition will cause more serious environmental problems due to the heightened abstraction of the water resources. Therefore, the opportunity cost of water (OCW) should be also high. Scarcity rent occurs in situations where the water resource is depleting. Actually, OCW and depletion premium (scarcity rent) have rarely been considered in the design of tariff structures. Although, a study in Spain (Berbel and Gomez-Limon, 1999) indicated that water pricing as a single instrument for control of water use is not valid means of significantly reducing agricultural water consumption, nonetheless it also suggested that water pricing is actually needed in order to make farmer aware of water resource scarcity, and to induce them to adopt water-saving technologies without affecting their selection of crops. Its objective is to lead the irrigated farming system become sustainable.

Despite, more groundwater irrigation systems that have been developed in Bali is seemingly in good operation, but facts show that a number of the others were not being operated. Therefore, the SDIABKA project was attempting to establish of efficient, economically and environmentally sustainable management of groundwater irrigation facilities for supporting household farming system (HFS) in coastal plain of two targeted regencies: Buleleng and Karangasem. The project that was being constructed 39 groundwater irrigation system involves approximately 1.560 farm-households. Despite, a groundwater irrigation system is appropriately succeed to encourage sustainable itself, it has yet to guarantee the irrigated HFS becomes sustainable since in accordance with Svendsen (*in* Pusposutardjo, 2004), the latter has actually wider than the former. Torres (*in* Torres and Shah, 1995) tried to add the reason that HFS not only embraces homestead agricultural activities but also homestead non-agricultural activities.

In addition to irrigation system technically inappropriate, unsustainable irrigated HFS could be occurred due to inefficient irrigated HFS since water pricing has yet to reflect the realities of scarcity or abundance of water. Water pricing, in case of SDIABKA project, seemingly only considers the operation and maintenance (O&M) cost. The contri-bution of users to investment and renewal is usually partial or zero. Preliminary data indicates that a scheme under the SDIABKA project usually serves 20 ha of mixed-farming which is operated by approximately 40 farm-households. The O&M cost of which is approximately Rp2 million per month, therefore the average price of water that is required to each farm-household is approximately Rp50,000 per month. Whereas, before the project was operated, some non-connected farm-households that used to collect water from spring must prepare to walk as far as two to six kilometers for round trip per day. The other some ones that collected water from vendors were usually willing to pay approximately Rp80,000 to Rp100,000 for a tank of water a week. It means that they seemingly have willingness to pay (WTP) at the higher rate per unit of water. But, only after they succeeded to obtain revenue that could be able to cover all their farm costs including full cost of water, did they WTP the water at rate of the sustainable value in use.

Therefore, this paper is an attempt to describe (1) technology of irrigation system assessment, (2) household farming system approach, and (3) economic-environmental approaches to agricultural resources analysis for sustainable irrigated agriculture, particularly in coastal plain of Bali.

IRRIGATION TECHNOLOGY ASSESSMENT

Gowing *et al* (1996) recognized that irrigation system existence is most important to provide one input to the agricultural system (i.e. water). Irrigation has especially seen as a supporting factor of government policy, in many countries for the success of agricultural develop-ment (Huppert and Walker *in* Osmet, 2002) and in Indonesia for the success of self-sufficient in rice program toward self-sufficient in food (INPRES 3/ 1999). Intensive and complementary use of irrigation water and others inputs has substantially increased the agricultural production in more favorable agro-ecological zones of Asia (Sugino, 2003), but increases of which have been associated with significant environmental problems that current production patterns cannot last forever because they depend on exhaustible resources (Joshi and Tyagi, 1991; Zilberman *et al*, 1997). Irrigation was also recognized success in supporting Green Revolution in Asia, even though irrigation schemes have often under-performed in economic term (Turral, 1995).

Irrigation infrastructure facilities have established possible by Govern-ment through heavy investment and the capital of which is derived from government earning or external financial sources in the form of loans and credit. It is not surprising that many countries have recently experienced a slowdown in food production due to stagnant irrigation development. Growth of irrigated areas has slowed sharply because (1) the existing favorable land frontier in Asia has almost been exhausted, (2) the exploitation of remaining irrigation potential is very costly and unbearable, (3) large-scale irrigation projects have raised environmental concerns, and (4) the maintenance of existing schemes has diverted public funds (Sugino, 2003).

Kaul and Sekhon (1991) stated that flexibility and reliability of irrigation are important factors in irrigated farming system. Compared with surface irrigation, groundwater irrigation systems are more reliable and flexible source of irrigation. Water supply flexibility and reliability refer to the ability of farmers to control water supply as and when desired. Tubewells for exploitation of groundwater have flexibility in the sense that these can be operated at any time according to requirement, provided the energy to operate these is available to the farmers. Then, reliability of groundwater can be seen from supply quantity, supply quality, and supply utility.

Supply quantity, for example in the eastern part of north coastal plain of Bali (5300 hectares), refers to the total volume of groundwater flow through that area approximately 30 MCM/yr which consists of base flow and annual recharge approximately 23 MCM and 7 MCM per year respectively. Thus, an abstraction of 25 percent of annual through flow is approximately 7,5 MCM/yr from 50 wells each pumping 20 l/s which represents an abstraction equivalent to estimated annual recharge therefore appears to be sustainable. The preliminary assessment indicates that existing groundwater use in project area is between 2 and 3 MCM/yr. Therefore, abstraction of 12 percent of annual through flow approximately 3.6 MCM/yr which would be sufficient to supply approximately 50 wells pumping at 10 l/s (assuming that wells are operated 10 hours per day for 180 days per year) is seemingly have a minor effect on the position of the interface and likely more environmental-friendly (Project Management Unit, 1995).

The groundwater quality objectives have been applied are either the current ambient concentration in groundwater which is considered necessary to protect the beneficial uses of groundwater. The environmental quality objectives require no degradation of the resource, and the possibility for improvement in groundwater quality (Barber, 1994). Then, the supply utility can be measured by further decom-position in order to consider three characteristics of the supply i.e. predictability, convenience, and tractability or controllability (Gowing *et al,* 1996).

In addition to flexibility and reliability, Kwaschick *et al* (1996) promoted appro-priate technology as one of determinant factors for sustainable irrigation system management. Appropriate technology refers to a technology package which must be technically feasible, economically viable, socially acceptable, environment-friendly, consistent with household endowments and relevant to the needs of farmers. Pusposutardjo (1997) stated that appropriate technology in water resources development with pump is very helpful and useful in increasing the local farmers' welfare especially for the groundwater pump irrigation systems of shallow and medium-depth, whose their capacities is in the amount of or less than 25 liters per second. However, deep ground-water irrigation system, technically, socially, and economically cannot appropriately managed by farm-household. Inappropriateness of which is firstly occurred due to financial-technical inability, then it encourages social in-appropriateness. As a result, the irrigation systems have become unsustainable.

HOUSEHOLD FARMING SYSTEM APPROACH

Sustainable agriculture as an integral part of sustainable development, conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, eco-nomically viable and socially accept-able (FAO Council *in* Kwaschik *et al,* 1996). In describing sustainable agriculture, Widodo (1998) stated that agricultural sustainability requires three in farming system: animal and crop productivities, socioeconomic viability, and the long term maintenance of resource base. Furthermore, Virmani and Eswaran (*in* Maji, 1991: 410) suggested some criteria for evaluating the sustainability of agricultural system. These include assessment of risk, assess-ment of production performance of the technology, stability of the system, impact of the farming system on the degradation of natural resources, particularly soil and water and the profitability of the system.

In attempting to the sustainable agriculture, Torres and Shah (1995) introduced household farming system (HFS) model as an its approach. FAO (1984) defined farming system as a system is managed by farmer and it usually involves a unique and reasonably stable arrangement of farming enter-prises that a household operates according to well defined practices in response to the physical, biological and socio-economic environ-ment and in accordance with the household's goals, pre-ferences and resources. Furthermore, Collinson (*in* Maji, 1991: 404) described that farming system is the way in which farm resources are allocated subject to the needs and priorities of the farmer in his local circumtances which include (1) agro-climatic conditions, such as the quantity, distribution and reliability of rainfall, soil type and topography, temperature, etc., (2) economic and institutional circumtances like market oppor-tunities, prices, institutional and infra-structural facilities and technology.

FAO (1985) has promoted a farming system embraces the farm (crops, livestock, forest, and pastures) and the farm-house-hold. Torres (*in* Torres and Shah, 1995) stressed that HFS embraces both homestead agricultural activities which can supported by irrigation system and homestead non-agricultural activities. Usually, a HFS has simply meant a farm operated and managed by the labor of one family, and may include a small amount of part-time hired labor. Some people refer to a family farm on the basis of acreage. Based on farming system definition above therefore irrigated mixed-farming in SDIABKA project area in Bali is a form of farming system development which is supported by groundwater irrigation system and operated by farm-households. However, defining HFS by size is misleading, because farming operations run by a farm-household range from a few acres of intensive vegetable farming to several thousand of acres of cattle range (Snodgrass and Wallace, 1977: 132-133).

The type of farming system adopted by the farmers is the result of allocating their limited resources, i.e. land, labor, and capital among different processes (farm and non-farm) that will maximize their income (FAO, 1986; Suraweera, 1988). Farm-household income is derived from crop, animal and other household productive activities. The mix and intensity of theses activities are the result of many decisions by each family about the allocation of its resources, the two most important of which are land and labor. Farming is also subject to physical, cultural and socio-economic policy influences, and dependent upon inputs and services from beyond the farm household boundary. The joint analysis of these factors, and the interactions among them, is the essence of a system approach to agricultural development, exactly to optimize the farm-household income (Dixon, 1988).

SUSTAINABLE VALUE IN USE OF WATER FOR IRRIGATION

Abernethy (1997) argued that water pricing will become more complex, incorporating more variable, and the charges them-selves will become higher. Present water pricing systems are usually simple. Often they are based only on a very rough calculation of the quantity delivered, and the rate is somehow related to the costs of the delivery process. The contribution of users to investment and renewal is usually partial or zero. Charges do not fluctuate much with the seasons, and do not reflect the realities of scarcity or abundance of water. Thus, in the coming decades it should expect to see water prices rising to levels that reflect better the actual cost of water resource development, also expect to see more sophisticated tariff structure.

ADB (1998) has illustrated the characteristic features of water supply in accord-ing to realize the appropriate levels of tariff and cost recovery in the water supply projects include the following: (1) water is usually a location-specific resource and mostly a non-tradable output, (2) market for water may be subject to imperfection, (3) investment are accruing in medium term (typically 10 years) phases and have a long investment life (20 to 30 years), and (4) water pricing has rarely been efficient.

The general principle of water cost that has sustainable dimension is promoted by Rogers *et al* (*in* Osmet, 2002). The water cost can be graded in to three levels, i.e. full supply cost, full economic cost, and full cost are shown in figure 1. This full cost serves as sustainable value in use.

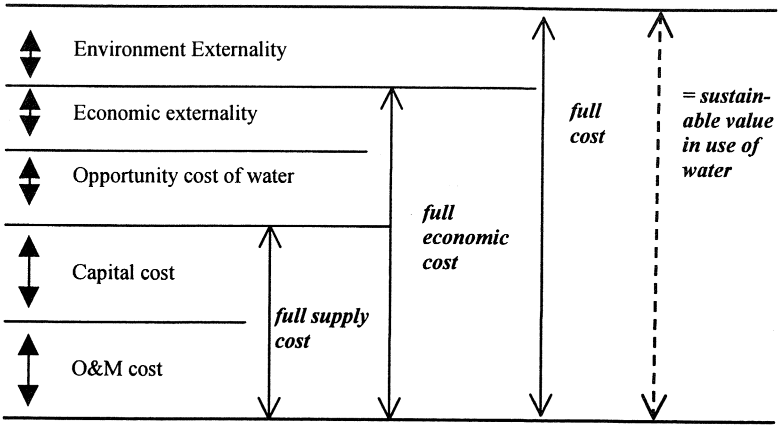

Figure 1. The general principle of water cost
(Rogers *et al* in Osmet, 2002)

The full supply cost is cost needed to supply water without counting the externality costs, which consists of the operation and maintenance (O&M) cost of the irrigation system and the capital cost (depreciation and interest). The full economic cost is the sum of the full supply cost, the opportunity cost of water, and the economic externality brought about. The opportunity cost is the value of water for the choice of other use. The economic externality cost is the cost of negative externality guaranteed by the third party as a result of water use. The water users should be responsible for the additional cost as a result of this negative externality. Then full cost, that is, the total cost consists of the full economic cost and the externality cost of the environment. The cost of environmental externality is cost brought about by water use which causes problems such as in community health and the environmental preservation.

In such cases, significant cost increase may take place as the aquifer stock depletes; the appropriate valuation of water has to include a depletion premium in the economic analysis. The depletion premium is a premium imposed on the economic cost of depleting resources, such as ground--water, representing the loss to national economy in the future of using up the resource to day. The premium can be estimated as the additional cost of an alternative supply of the resource or substitute, such as rainwater storage, when the least-cost source of supply has been depleted. In this case, the time until exhaustion is assumed to be 25 years and the alternative source to replace the groundwater is rainwater storage to be brought from a long distance. The formula to calculate the scarcity rent is as follows:

$$Depletion\,premium = (C_2 - C_1)e^{-r(T-t)},$$

where C_2 = cost of water per m^3 of alternative source; C_1 = cost of water per m^3 of exhausting source; T = time period of exhaustion; t = time period considered; rate of discount ($r = 0.12$); and e = exponential constant = 2.7183. As can be seen, the premium or scarcity rent increase each year as the stock of water diminishes (ADB, 1998).

Since the market for water may be subject to imperfection that was likely characterized by ADB, hence Fujita and Hossain (1995) previously tried to draw it under assumption of monopoly. The profit P which accrues to the tubewell (TW) owner during an irrigation season is defined as follows;

$$P = wA - cA - F,$$

where A is the acreage of the water sold (assuming that all the water is sold), w is the water charge per acre, c is the variable cost per acre for TW operation, and F is the fixed capital cost of a TW during an irrigation season.

Assuming the water seller holds a monopoly and his behavior is to maximize profits, the equilibrium water charge w^* is obtained as follows;

$$w^* = e/(e-1) \cdot c,$$

where e represents the price elasticity of the demand for water. This relation is shown diametrically in figure 2. Demand for water (*D*) is the derived demand from irrigated agriculture by non-owner farmers. The marginal revenue curve for the TW owner (*MR*) is derived from *D* under the assumption of monopoly. At the intersection of the marginal cost curve (*MC*) and *MR*, the acreage of water sold A^* is determined along with the water charge w^*. Defining net irrigation surplus (*NIS*) as the surplus from which all the material and labor cost (including family labor cost imputed by the prevailing market wage rate) have been deducted from the gross revenue of agricultural production, *NIS* is equivalent to the shadowed area in figure 2.

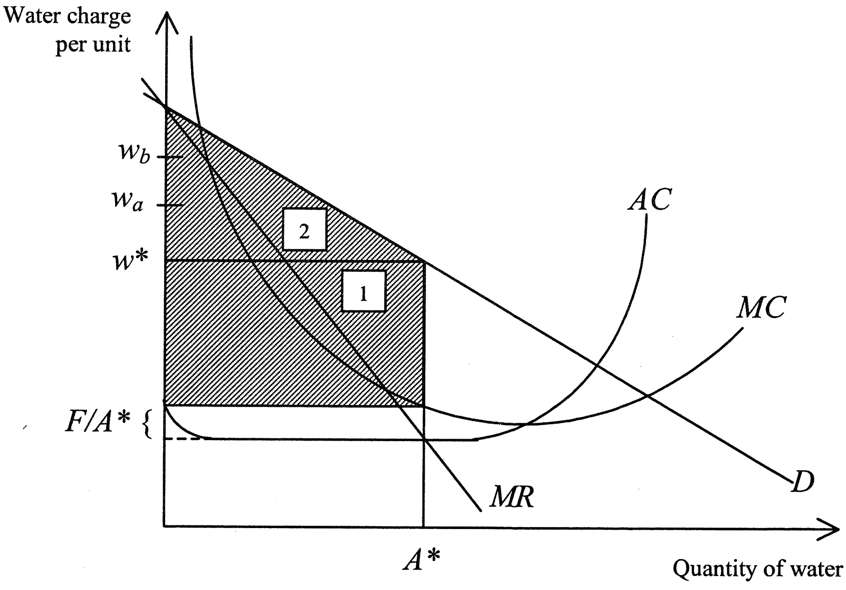

Figure 2. Water pricing and net irrigation surplus or total benefit (Pearce and Turner, 1990; Fuji and Hossain, 1995)

In accordance with Pearce and Turner (1990:126), *NIS* is total benefit and its amount obtained is in fact the entire area under the demand curve by the two shaded areas. The shaded area 1 is the total expenditure by individuals on this particular water, and the shaded area 2 is the consumer surplus. w^* becomes the market price of water for everyone since it is not possible to change a different price (charge) to each and every individual buying the water. But individual *A* can be seen to be willing to pay (WTP) a higher price, w_a. Similarly, individual *B* is WTP a price w_b, so this condition will generate the consumer surplus. In theory *NIS* is composed of land rent, interest on capital, and profit (Fujita and Hossain, 1995). Shah (*in* Fujita and Hossain, 1995) regarded the value of $e/(e - 1)$ $(=w/c)$ as a good indicator of the extent of monopoly held by TW owners in the groundwater market.

EXTENDED COST-BENEFIT APPROACH

Cost-benefit analysis (CBA) is one of relevant approaches which offer promise for assessing natural resource and environmental management in developing countries. In addition to it can be divided into financial and economic analysis, CBA is also classified into conventional and extended CBA. Conventional CBA is an essential tool for economic analysis of projects and most applicable in the construction of physical infrastructure including dams and other irrigation facilities. Environment effects are not included unless they can be shown clearly in monetary terms through direct impacts on economics efficiency therefore conventional CBA needs to be extended and broadened as namely extended CBA (Hufscmidt, 1979).

The basic difference between the financial and economic CBA of a project is that the former compares benefit and cost to the enterprise in financial prices, while the latter compares the benefit and cost to the whole economy measured in economic prices. Financial price are market prices of good and services that include the effects of government intervention and distortions in the market structure. Economic prices reflect the true cost and value to the economy of good and services after adjustment for the effects of government intervention and distortions in the market structure through shadow pricing of the financial price (Kadariah *et al*, 1978:3; Gittinger, 1986: 24; ADB, 1998).

Financial benefit-cost analysis is not differ in both conventional and extended benefit-cost analysis. The financial benefit-cost analysis includes the following eight steps (ADB, 1998) as follows: (1) determine annual project revenues, (2) determine project costs, (3) calculate annual project net benefits, (4) determine the appropriate discount rate (i.e., weighted average cost of capital - *WACC* as proxy for the *FOCC*), (5) calculate the average incremental financial cost, (6) calculate the financial net present value (*FNVP*), (7) calculate the financial internal rate of return (*FIRR*); and (8) risk and sensitivity analysis.

The *WACC* is calculated first by estimating the nominal cost of the different sources of capital. The *WACC* in nominal terms is obtained by multiplying the nominal cost of each source of capital after tax with its respective weight. The *WACC* in nominal term is corrected for inflation to form the *WACC* in real terms (ADB, 1998; Husnan and Muhammad, 2000: 248-251):

$$WACC_{nom} = \sum_{i=1}^{n} WC_i \times CCAT_i$$

$$WACC_{real} = \frac{1 + WACC_{nom}}{1 + \inf.\, rate} - 1$$

where *WC* is proportion (weighted) of each source of capital; *CCAT* is nominal cost of each resource of capital after tax; *i* =1, 2, ...n are source of capital, for example, loan (long term credit), working capital (short term credit), and equity, and *inf. rate* is rate of inflation.

The difference between conventional and extended CBA is put on the economic CBA in relation to the external effects in benefit and cost of a project (table 1). There are many examples of such externalities that are not accounted for in market transactions and that are, therefore, not directly reflected in the financial cash flow of a project. The environment impact of a project is a typical example of such an externality (ADB, 1998).

Assessing profitability of the project in extended CBA terms is given to utilize investment criteria. There are five investment criteria, i.e.: (1) net present value (NPV), (2) internal rate of return (IRR), (3) net benefit-cost ratio (Net B/C), (4) gross benefit-cost ratio (Gross B/C), and (5) Profitability Ratio. NPV, IRR and Net B/C are satisfied investment criteria for the special use, while Gross B/C and profitability Ratio are faced some critiques theoretically (Kadariah *et al,* 1978:28).

Formulation and criteria of NPV and IRR are served as follows (Kadariah *et al,* 1978:29-30, Moya, 1981:14; Moya *et al,* 1981:5):

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t}$$

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+IRR)^t} = 0\,.$$

Profitability of the project can be seen in both financial and economic CBA. Financial CBA of the project involves estimating the financial net present value (*FNVP*) and the financial internal rate of return (*FIRR*) in constant prices. The *FIRR* is the rate of return at which the present value of the stream of incremental net flows in financial prices is zero. Then, the *FIRR* should be compared to the *WACC*. If the *FIRR* exceeds the *WACC*, the project is considered to be financially viable. If the *FIRR* is below the *WACC*, the project would only be financially viable if subsidized by the government. The financial net present value (*FNVP*) shows the present value of the net benefit stream, or the projects' worth today. The discount rate to be used here is the

WACC. A positive *FNVP* indicates a profitable project, i.e. the project generates sufficient funds to cover its cost, including loan repayments and interest payments.

Table 1. The difference between the financial and economic CBA

ITEMS	Benefit-Cost Analysis		
	Financial Analysis	Economic Analysis	
		Conventional	Extended
Objective	To estimate private return during the project lifetimes	To estimate economic return during the project lifetimes	To estimate economic return during the project lifetimes
Indicator	Financially sustainable	Economic efficiency	Economic efficiency
Price use	Financial/market price	Shadow pricing of the financial price for direct use valuation	TEV = actual (direct & indirect) use value + option value + existence value
Capital treatment	Initial investment and salvage value	Initial investment and salvage value	Initial investment and salvage value
Off-farm & Non-farm incomes	Included	Included	Included
Outputs that are consumed by H'hold	Included	Included	Included
Discount rate	*WACC* as proxy for the *FOCC* in market	*EOCC* or *SOCC*	*EOCC* or *SOCC*
Environment impact (externality, quality and sustainability)	Excluded	Excluded	Included
Taxes, subsidies, credit receipts, debt services treatment	Included	Transfer payment	Transfer payment
Opportunity cost	Excluded	Included	Included
External cost and depletion premium (scarcity rent)	Excluded	Excluded	Included
Performance indicators	FNPV and FIRR	ENPV and EIRR	Extended (ENPV and EIRR)

Notes: *TEV = total economic value, H'hold = household, WACC = weighted average cost of capital, FOCC = financial opportunity cost of capital, EOCC or SOCC = economic or social opportunity cost of capital, FNPV = financial net present value, FIRR = financial internal rate of return, ENPV = economic net present value, and EIRR = economic internal rate of return.*

Economic CBA embraces estimating the *EIRR* or economic net present value (*ENVP*) discounted at economic or social opportunity cost of capital (*EOCC* or *SOCC*)=12 percent by comparing benefits with the costs. The *EIRR* is the rate of return for which the present value of the benefit stream becomes zero, or at which the present value of the benefit stream is equal to the present value of the cost stream. For a project to be acceptable, the *EIRR* should be greater than *EOCC*. ADB uses 12 percent as the minimum rate of return for projects; but for projects with considerable non-quantitative benefits, 10 percent may be acceptable (ADB, 1998).

The rational behind accepting investment with a positive NPV can be explained two ways. *First*, it means the actual rate of return on the investment is greater than the opportunity cost of capital if that was used as the discount rate. *A second* explanation is that the investor can afford so pay more for the investment and still achieve a rate of return equal to the discount rate used in calculating the NPV. In addition to rather difficult calculations involved, there is another potential limitation on the use of IRR. It implicitly assumes the investment can be reinvested to earn a return equal to the IRR. If the IRR is fairly high, this may not be possible, causing the IRR method to overestimate the actual rate of return (Kay, 1981).

LINEAR PROGRAMMING APPROACH

Production function shows technical interrelation between input and output. The specific forms of production function are consists of three types, i.e., the Cobb-Douglas (C-D), input-output (I-O), and linear programming (LP) production functions (Yotopoulos and Nugent, 1976).

Essentially, LP is formal mathematical technique which selects the combi-nation (and the levels) of activities, from the set of all feasible activities, such that a specified objective function, usually the cash surplus, is maximized without violating the resource and any other specified constraints (Barlow *et al*, 1977). According to Cohen and Cyert (1976: 360), LP is a term that describes constrained optimization problem in which the objective function and the constraints are linear in nature.

In applications of linear programming, the following fundamental assumption must be present if the model is to be properly formulated and the results obtained meaningful [Dantzig (1975:288-289); Cohen and Cyert (1976: 362); Subagyo *et al* (1983); Debertin (1986: 332-333)]: (1) divisibility, (2) additivity, (3) proportionality, (4) non-negativity, (5) linearity, and (6) deterministic (certainty), single-valued expectation.

The primary advantages of LP are that: (a) it is possible to include almost as many activities and constraints as seem appropriate to realistically represent a given farm situation; (b) it optimizes in terms of specified objective function usually total cash surplus; and (c) the better LP computer programs include facilities that enable important parameters in the model to be varied in a desired fashion and to investigate the effects of such changes on the optimal solution. But, LP also has several limitations, i.e., (1) the major dis-advantage of LP is the need for access to a computer, and large amount of reliable data, and (2) some of the assumptions in the method may limit the applicability of the technique, i.e. assumptions of linearity, constant returns to scale and use of single-valued coefficients implying risk is not explicitly considered (Jayasuriya and Price *in* Gonzales, 1983). Another limitation of LP in accordance with Hartono

(2004:3) that LP model is deterministic because all parameters in the model are known certainly, whereas in reality the parameter without error (certain parameter) is rarely found. In application, the LP model which is a normative model usually uses random sampling method to obtain the average (existing) condition, whereas old approach of LP always uses the best sample. Data that are obtained from sampling method is probabilistic nevertheless it is assumed deterministic. As an attempt to reduce the limitation and to elicit the validity of LP model hence data must be lied in confidence interval and then to conduct sensitivity analysis in order to examine sensitivity of model toward some changes in parameters value.

Farmers seeking to maximize profits will use water and other variable inputs at levels where the incremental value generated is equal to the incremental cost. Farmers also will choose cropping patterns that maximize net returns, over time, subject to their resource endowments, relative input and output prices, and marketing oppor-tunities. In regions where farm-level water supplies are scarce, relative to available land, farmers will choose crops that maximize net returns to their limited water supplies. If land is scarce, while water is relative abundant, farmers will choose crops that maximize net returns per unit of land. Farm-level choices regarding water management will vary with the cost and availability of water and of methods for improving irrigation efficiency (Wichelns, 2001:238).

Many studies utilized LP as an optimization technique to determine optimal solutions related to fresh water irrigation issues such as maximizing net benefits, minimizing costs, determining optimal cropping pattern, daily operation decisions for irrigation water delivery, and water management strategies for salinity control on farm or regional level. Segarra *et al* (*in* Darwish *et al*, 1999) used a linear dynamic programming model to determine the cropping pattern that would remove all the nitrogen from secondary treated effluent and maximize revenues over variable costs. Darwish *et al* (1999) then used LP to determine the optimal cropping pattern that utilizes all or most the secondary treated wastewater available, consumes all the nitrogen available in this treated wastewater (being the most limiting factor), and produces the highest net return for the selected study area.

Linear programming analysis in this discussion is to maximize the cumulative net value of available income generated by the model sustainable household farming system based on groundwater irrigation (LP-SHFSGW model) over a period (*t*) of *T* years (Budiasa, 2005). This LP-SHFSGW model which would be developed is an ideal and extended optimization model for sustainable irrigated agricultural system. Consequently, this analysis is not only mulled over an economical dimension, but it is an attempt to incorporate and analyze social as well as environmental dimensions into model. The model is based on farmers active participation, regard the farm-household as the farming unit, and integrated, in that, the animals are reared for work, manures, draft purposes, meat, and other products. Crops are grown for commercial products and/or forage or crop residues that are used as feed. Important by-products are farmyard manure and dung dropped in the field and used for maintenance of soil fertility.

ANALYSIS FRAMEWORK

Criteria and procedures for assessing the sustainability of household farming system based on groundwater irrigation in the eastern part of the north coastal plain of Bali are drown in form of analysis framework (figure 3). First major analysis is that to assess the appropriateness of representative groundwater irrigation system under the SDIABKA project. Appropriate technology as one of determinant factors for sustainable management of irrigation system can be seen from whether its existence is technically feasible, economically viable, socially acceptable, environment-friendly, consistent with household endowments and relevant to the needs of farmers. Strongly appropriateness can be occurred if the irrigation system is also supported by its flexibility and reliability. Technically-feasible refers to the ability of farmers to operate the system based on simple rules and procedures at any time according to water requirement. Therefore, technically-feasible is also mean the flexibility of the irrigation system. Economically- viable is determined from the result of cost-benefit analysis toward the groundwater irrigation system. Socially-acceptable refer to its existence is utilized for supporting household farming activities as well as for domestic water supply. Acceptability is also shown from prepared of farmers to establish water user group (*subak sumur pompa*) and rules for managing water resources optimally and fairness. Environment-friendly refers to the extraction of groundwater is not higher than its recharge and its quality can to fulfill the minimum standard water quality for domestic water supply and irrigation. Then, reliability of the irrigation system refers to supply quantity, supply quality, and supply utility.

The underlying table 2 describes analysis methods that can be done in order to assess the sustainability of irrigated household farming system. Extended cost-benefit analysis (CBA) that embraces both financial and economic analyses and internalizes social and environmental cost and benefit into economic analysis is conducted based on basic elements of farm investment analysis during the project lifetimes (usually 20 to 25 years for irrigation projects). The basic elements of farm investment analysis are include agricultural resources (land, labor, water) use, farm (crops and livestock) output and their values, farm input (investment as well as operation and maintenance expenditures for irrigation and farming activities), and detail irrigated farming budget with and without project condition (Gittinger, 1986: 116, 154-155).

Secondly, major analysis in this paper is to optimize the LP-SHFSGW model. It is needed to remember that HFS operation is influenced by internal factors is that farm-household resources and external factors i.e., physical factors and technical-economical-institutional factors. Household individually will to plan their activities precisely to obtain the highest land use efficiency with groundwater irrigation support. In the event that individual HFS is technically appropriate, economically viable, socially acceptable, environmentally non-degrading, therefore it is called sustainable irrigated HFS. Technically appropriate refers to management practices and procedures including irrigation technology and low external input of sustainable agriculture (LISA) in mixed-farming system can be conducted by farm-household. Viability of HFS individually is assessed from the result of optimizing of LP-SHFSGW model. Managing HFS in group that is supported by social capital likely water user group/association (or *subak* system particularly in Bali) and some rules is an attempt to manage the system optimally and fairness, therefore it means socially-acceptable. Environmentally non-degrading refer

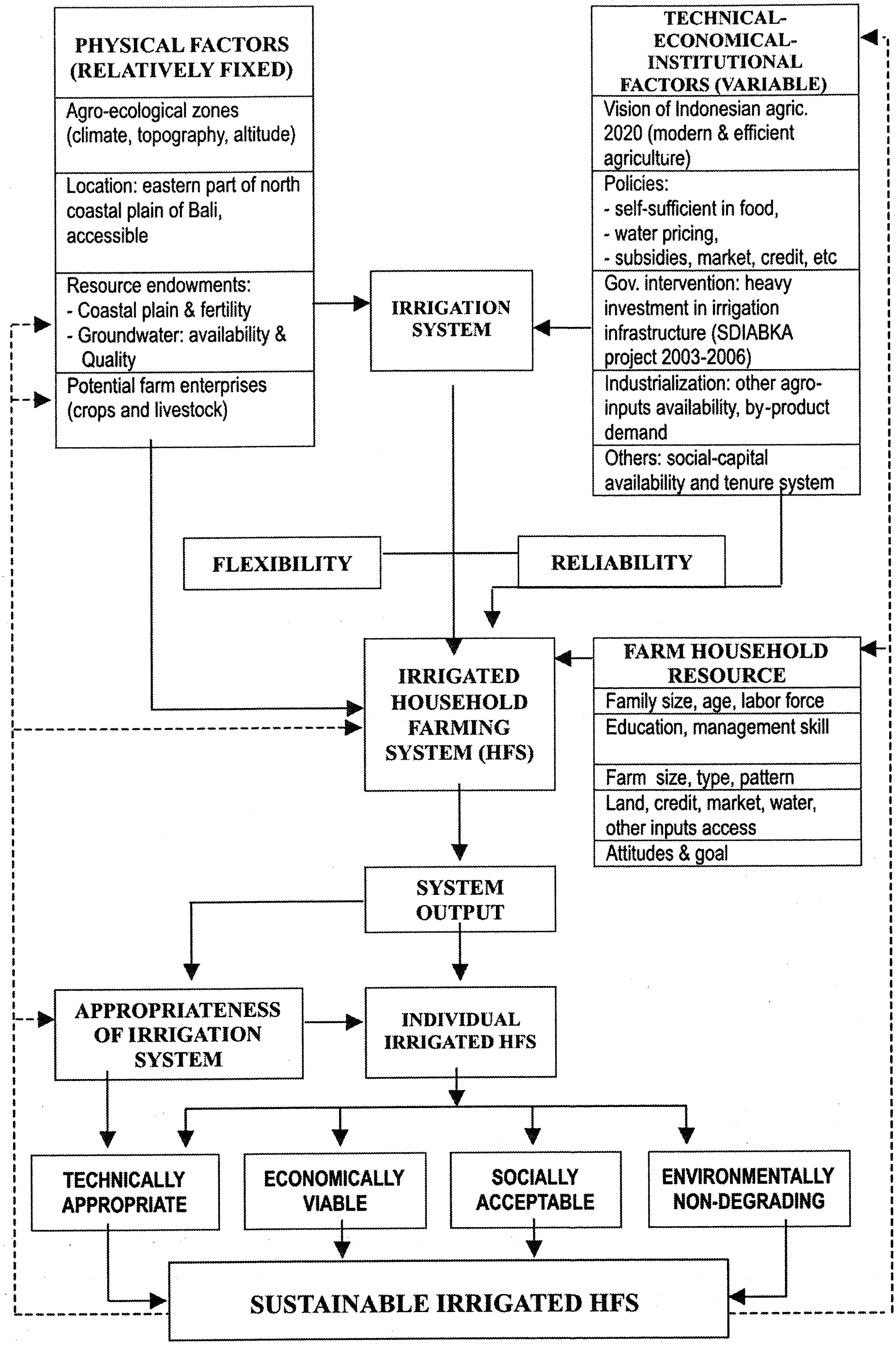

Figure 3. Analysis framework for sustainable HFS model, SDIABKA project

Table 2. Analysis methods for sustainable HFS, SDIABKA project

Objectives	Kind of analyses	Analysis Tools
To assess appropriateness of groundwater irrigation system		
(1) technically – feasible	-Descriptive analysis	-Irrigation map and scheme, feasibility of O&M procedure, and distribution of water
(2) economically – viable	-Extended Cost-Benefit Analysis	-Microsoft excel
(3) socially – acceptable	-Descriptive analysis: (institutional support, training and capacity building,)	-Structure of WUA and the utilization of groundwater
(4) environmental – friendly	-Laboratory analysis	-Groundwater quality standard for domestic water supply and irrigation
To optimize LP-SHFSGW model	Linear programming (LP) analysis	$BLPX_{88}$
Water pricing	Match analysis	Formula: Rogers *et al* (*in* Osmet, 2002) and Fuji and Hossain (1995)
To examine the influence of prices and technologies changes on irrigated HFS	Sensitivity analyses in both Extended CBA and LP	Microsoft excel and $BLPX_{88}$

to the operation of HFS with the best management practices based on maximum groundwater extraction including LISA effects to natural resource preservation, particularly for soil and water resources.

Variables for LP-SHFSGW model including:

(1) Objective function is to maximize the cumulative net value of available income from mixed-faming, sales, consumption, finance and off-farm activities under LP-SHFSGW model over a period (*t*) of *T* years subject to land availability, labor, capital, kind and quantity of perennial crops as well as livestock, and maximum groundwater outward flow and maximum used of inorganic fertilizers and pesticides into the best management practices (BMPs).

(2) Activities including of crops as well as livestock production with BMPs, food and non-food consumption, processing of agri-cultural product, sales of crop and livestock products, buy agricultural inputs (including the irrigation water and extra labor), financing (credit, allocation and transfer of money) and off-farm employment (including participatory farmer extension and training) activities. All activities will be calculated on the annual basis that would be divided into 12 (twelve) months activities during *T* years.

(3) Constraints. Agricultural land constraint (ha) is average of land that have used by each farmer or member of WUA. Family labor constraint (man-days) is average available labor in each farm-household. Maximum outward flow of groundwater and crop water requirement (*CM*) is to ensure recharge process for groundwater as a resource that can be depleted. Maximum applied of chemical fertilizer and pesticide (kg or l) refers to low external input of sustainable agriculture (LISA). Number of perennial crop (tree) and livestock (head) are average of its equivalent with productive crop and an adult livestock or mother of animal, respectively. Consumption constraint (kg or head) for essential food crop or livestock consumption that all or partly have produced by themselves or in monetary for non-food and food consumption which could not measured in the same unit. Minimum house hold expenditure (Rp) for basic need of all member of family per annum. Maximum others earning (Rp) that could be earned by each family per annum. Capital constraint is maximum formal or informal credit per year/season, salvage of formal and informal credit from month to month, and total of money that in or out to each activities.

(4) Input-output coefficient for each activity will be obtained from the result of data tabulation.

Based on the above explanation, a basic form of the LP-SHFSGW model is presented herein.

Maximize:

$$I=\sum_{t=1}^{T}\left(\sum_{k=1}^{n}P_{kjt}Q_{kjt}-\sum_{k=1}^{n}r_{kjt}A_{kjt}+NOFI_{jt}-mM_{jt}-HE_{jt}\right)(1+r)^{-t}$$

for $t=1\ldots T$

Subject to:

(1) Agricultural land available constraint

$$\sum_{t=1}^{T}\sum_{k=1}^{n}X_{kjt}\le LAV_{jt}$$ for all month j and period t, $j=1\ldots12$ and $t=1\ldots T$

(2) Groundwater flow constraint

$$\sum_{t=1}^{T}\{(\sum_{k=1}^{n}CWR_{kjt}\times X_{kjt})+(\sum_{k=1}^{n}ANWR_{kjt}\times HAN_{kjt})+DWS_{jt}\}\le GWF_{jt}$$

for all month j and period t, $j=1\ldots12$ and $t=1\ldots T$

(3) Labor force available constraint

$$\sum_{t=1}^{T}(F+NOF+FMET)_{jt}\le LFAV_{jt}$$ for all j and t, $j=1\ldots12$ and $t=1\ldots T$

(4) Transfer activity

$$\sum_{t=1}^{T}\sum_{k=1}^{n} q_{kjt}A_{kjt} - Q_{kjt} \geq 0 \quad \text{for all } j \text{ and } t, j = 1 \ldots 12 \text{ and } t=1 \ldots T$$

(5) Working capital balance

$$\sum_{t=1}^{T}\sum_{k=1}^{n} r_{kjt}A_{kjt} + mM_{jt} + HE_{jt} - M_{jt} \leq SM_{jt} \quad \text{for all } j \text{ and}$$

$t, j = 1 \ldots 12$ & $t=1 \ldots T$

(6) Household consumption expenditure constraint

$$HE \geq C$$

(7) Credit constraint

$$M \leq B$$

(8) Non-negativity constraint

$$Q_k,\ A_k,\ M \geq 0 \quad all\, k = 1, 2, \ldots. n$$

where:

I = cumulative net value of available income
Q_k = sales of commodity k
A_k = Activity to produce Q_k
M = credit borrowing activity
X_k = Crop commodity k
CWR = Crop water requirement
$ANWR$ = Animal water requirement
DWS = Domestic water supply
F = Farm employment
NOF = Non and/or off-farm employment
$FMET$ = Farmer meeting, extension and training
$NOFI$ = Non and/or off-farm income
HE = value of household expenditure
C = minimum household consumption expenditure
B = maximum borrowed capital
SM = Own capital
P_k = Price of product Q_k
r_k = Cost of each unit activity A_k
m = Capital cost
q_k = Production for each unit of activity A_k

For the model runs presented in this paper, the optimization period T is 20 years. This is considered a reasonable decision time frame when heavy re-investment problem on the pump and others equipment of groundwater irrigation system are involved.

SUMMARY AND CONCLUSION

Some summaries and conclusions can be generated based on the theoretical and analysis frameworks are as follows:

(1) Irrigated household farming system (HFS) in eastern part of north coastal plain of Bali embraces two interrelation systems, i.e. groundwater irrigation system and household farming system. Therefore, irrigated HFS is wider than groundwater irrigation system since irrigated HFS embraces both homestead agricultural activities which can be supported by groundwater irrigation system and homestead non-agricultural activities. Thus, assessment concept for sustain-able agriculture is addressed to irrigated HFS in coastal plain.

(2) Groundwater irrigation system is a form of technology. Technology assessment for groundwater irrigation system is the first way to assess the sustainability of irrigated household farming system (HFS). It is not an appropriate technology if one or some criteria, i.e. economically-viable technically-feasible, socially-acceptable, and environmental-friendly can not fulfilled. Economically-unviable of which, for example, is due to revenue that could not be able to cover all farm costs including full cost that reflects the sustainable value in use of water. Without the appropriateness of irrigation system, therefore the irrigated HFS is not become sustainable.

(3) Linear programming - sustainable household farming system based on ground-water irrigation (LP-SHFSGW) model is established as an attempt to optimize the utilization of agricultural resources (land, water, germ plasma, labor, capital, and technology) at the household farming system level in SDIABKA project area with consider economic-environmental aspects into model.

(4) Two economic-environmental approaches to agricultural resources analysis are recommended in order to assess the sustainability of irrigated agriculture, particularly in coastal plain of Bali, i.e. extended cost-benefit analysis for technology assessment and linear programming analysis in order to optimized LP-SHFSGW model. Sensitivity analysis is also needed in order to examine sensitivity of both models toward some changes in parameters value. Some supplementary analyses useful to complete entire analysis i.e. descriptive and laboratory analyses.

(5) Existing charge (price) for water in the project area is not sustainable value in use of water, therefore it strongly encourages to unsustainable condition for LP-SHFSGW model.

(6) In the event that the groundwater irrigation system is economically viable, its estimated that it is strongly sensitive to any changes, i.e., an increase 20% in investment and O&M cost, as well as charge for water, a reduction 20% in the economic benefits, and a reduction in the lifetime of the investment.

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