Financial appraisal of efficiency investments: Why the good may be the worst enemy of the best

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Abstract
This methodological paper has a didactic goal: improving our understanding of what "cost-optimal energy performance of buildings" means, and how financial appraisal of efficiency investments must be set up. Three items merit improvement. First, focus on the endowment character of energy performance of long-living assets like buildings. Second, defining cost-optimal requires more than a comparative static trade-off scheme; cost-optimal refers to dynamic efficiency, which results from technology dynamics induced by changes in society and policy. Third, financial appraisal is a more complex issue than simple net present value and life cycle cost calculations. It must reflect the time sequential dynamics of real life processes including real life decision-making. Financial appraisal is embedded in a complex framework made up by three dimensions: future time, doubt and irrevocability. The latter dimension connects with issues like lock-in, path dependency, generally overlooked in net present value calculations. This may lead to very erroneous recommendations regarding efficiency investments, in particular when the energy performance endowment of buildings is decided. The paper introduces the literature. Mostly irrevocability is used as an argument to "Wait and Learn" with disastrous impacts on the pace of climate policy. But the opposite "Choose or Lose" is the logical outcome when the methodology is fed with evidenced expectations. The latter boosts energy efficiency to its boundaries, saving it from the middle-of-the-river quagmire where incomplete appraisals are dropping it too often (making the good the worst enemy of the best).

Introduction
In debating what levels of energy efficiency are "optimal" financial-economic arguments have a big stake. Investors and operators search for levels of energy use, casu quo energy efficiency, that are expected to be least-cost. Public decision-makers argue that their mandated regulations are cost-effective or cost-optimal. The Energy Performance of Buildings Directive 2010/31/EU (EPBD) is a case in point, and will be quoted as an example that lacks a clear definition of what cost-optimal could mean.

This article has three main parts, followed by a conclusion. The first part spells out the three dimensional framework that is needed to situate decisions and investment decisions (figure 1). It is made up by the dimensions; future time, doubt and irrevocability. The dimensions are discussed one by one, although analysis is based on their interaction. Most attention is devoted to irrevocability because not that many scholars are familiar with it, and it is mostly overlooked in practical studies, what can lead to "very erroneous" recommendations (Dixit and Pindyck 1994). Like time and doubt, the factor irrevocability also "comes in degrees" (Verbruggen 2011). Therefore a metric of irrevocability as strong (preclusion), medium (rigidity) and weak (flexibility) is proposed (figure 2).

The second part delves into the terminology "cost-optimal energy performance of buildings". It argues that comparative statics (BPIE 2010) offers but a textbook trade-off scheme to explain the impact direction of cost drivers. It does not meet the challenge of assessing cost-optimal in the dynamic contexts of the real world. For a (better) consideration of the dimension irrevocability it is necessary to extend the term energy performance with the concept of endowment, and put the emphasis on the latter when studying long-living assets with an important energy efficiency heritage. Buildings are a clear example why refinement of our vocabulary is preferable.

The third part introduces the basic concepts of investment appraisal taking into account time sequential dynamics. With simple binary choice, two-period examples the standard case of "Wait and Learn" and the new case of "Choose or Lose" are presented and opposed. The second case is prevalent when waiting is not possible or no longer an option, and when irrevocability has a significant impact. While the two applications deliver opposite advice to the investor, they are the result of a single methodological approach.[1]

The conclusion wraps up the major findings of the article, but is put under the title "the good as worst enemy of the best", because the findings signal the real danger that this happens when irrevocability is not considered.

A three-dimensional framework embeds investment decisions

Financial appraisal (Bierman and Smidt 1971) is a structured way of processing assessed flows of expenses and revenues over time resulting from a decision (investment). The analysis is extended to a cost-benefit analysis (CBA) when non-market (un-priced) aspects are included (Layard ed. 1972). The term cost-benefit analysis is used wrongly or loosely when non-market aspects are neglected or but partially included, which is generally the case.

When a private economic agent is investing, a CBA means that difficult to measure values (comfort levels, amenities, security, etc.) are monetized and included in the financial appraisal. An inherent difficulty is how reliable and complete the assessments of the costs and benefits related to the decision are. From a societal point of view the CBA must cover all costs and benefits to society wherever and whenever they fall upon whoever. Neither the public nor private CBA perspectives are adopted in the EPBD (EU 2010), given Art. 2 states: "the lowest cost is determined taking into account energy-related investment costs, maintenance and operating costs (including energy costs and savings, the category of building concerned, earnings from energy produced), where applicable, and disposal costs, where applicable". This contribution will stick to the reduced EPBD approach, although being less favorable for efficiency options that provide more intangible benefits than energy wasting equipment and apparatus. The advantage of the narrowed scope however is that we can focus on the bare methodology of financial appraisal, generating already enough material for study, discussion and clear conclusions.

Decisions can only be made for the future, and by definition the future is uncertain. For day-to-day, simple, and transient actions suffices our intuitive decision processor. But for long-term, complex, and persistent investments only correct, scientifically based methods are adequate (Matheson and Howard 1968). Constructing a solid building is a unique and complex decision with wide-ranging, lifetime consequences. Overcoming spatial and temporal myopia is the challenge for enlightened and successful decision-making. It is helpful to consider investment decisions in a three-dimensional context (figure 1). Each dimension requires case-dependent elaboration with due regard for the interactions with the other dimensions. The three dimensions are time, doubt, and irrevocability.

1. In lectures for a technical public I refer to the metaphor of the thermodynamic compression-evaporation cycle: used for cooling with a refrigerator and for heating with a heat pump (the latter is also used in reverse for cooling).

FUTURE TIME

First, future time: one only can decide for the future because the past cannot be changed whatsoever. Analyzing investment opportunities is an exercise in looking into the future. Who looks how far, at what, and for what in the future is case dependent. The time axis of figure 1 mentions years – decades – centuries, which in a building's case corresponds to appliances, equipment, constructions, and infrastructure. Many architects have acquired familiarity with discounted cash flow tables and calculations, and profusely use the discounting operator (Bierman et al. 1977; Jelen and Black 1983; Rushing and Lippiatt 2008). Discounting is the inverse of exponentially growing compound interest. Therefore discounting at a positive rate represents exponential decay. Let:

H = project Horizon in number of years (index j)

dr = yearly discount rate expressed as a positive decimal (e.g. 0.03 for 3 %)

RB_j = Revenues/Benefits of the project in year j expressed in monetary units

EC_j = Expenditures/Costs of the project in year j expressed in monetary units

The discounted value of the net cash flows occurring in the project's lifetime from year 0, the initial year or year of initial investment EC_0 to the horizon year H, equals the Net Present Value NPV or:

$$NPV = \sum_{j=0}^{H} \frac{(RBj - ECj)}{(1+dr)^j} \qquad (1)$$

The formula shows that the obtained NPV outcomes depend on the actual cash flows in the various years, and on the parameters dr and H. To emphasize the role of the parameters one may write NPV as $NPV(RB_j, EC_j \mid dr, H)$. NPV is a proper standard to measure the performance of a project over a time period {0 – H} because it includes all revenues/benefits and expenses/costs at the moment of their occurrence and it assigns a time value to that moment by applying the discounting operator. There is little unanimity on the best choice of the discount rates dr, and the fixing of the time horizon H is often arbitrary (Portney and Weyant, eds. 1999). Both choices are interrelated because H has more weight when dr is lower, and vice versa.

DOUBT

Second, doubt: the future is by definition unknown and there is doubt about expectations and forecasts of what the future will bring. Doubt is due to our incomplete knowledge about

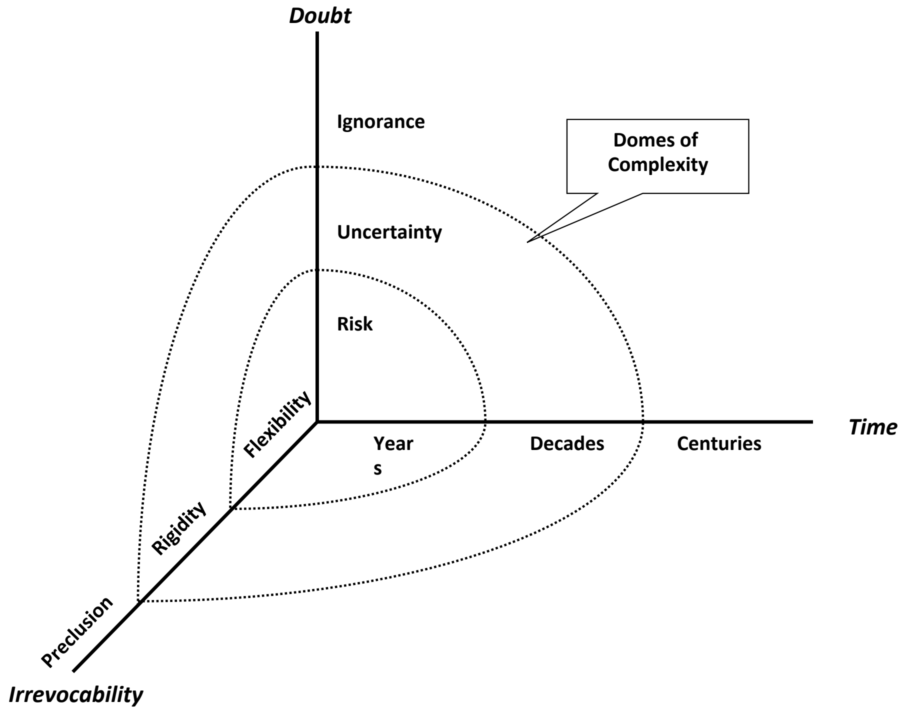

Figure 1. Three dimensions determine the complexity of investment appraisals.

events that may happen and of the likelihood or probability of occurrence of the events. Depending on the subject, on the investigated aspects and on the distance in time, three levels of doubt can be identified: risk, uncertainty, and ignorance (table 1). Risk is the most informative level: the relevant future events are recognized and the probabilities of their occurrence are assessed, based on long-time experience and on scientific evidence. Uncertainty has a good record of possible events too, but very little information about probabilities that therefore must be assessed in a subjective way (for example expert opinions). Ignorance is deeply problematic because future events cannot be forecasted, a fortiori not their probabilities. Ignorance must be considered when the likelihood exists that at this moment unknown events important for our decisions may emerge in the future (Munasinghe et al. 1995; Stirling 1999).

A building planner enjoys mostly the relative comfort of shallow doubt: most risks can be inventoried and modeled. Uncertainty concerns drastic changes in economic policy regarding the use of fossil fuels, affecting significantly future prices of fossil fuels and of grid power. Also ignorance about future technologies or about catastrophic impacts triggered by climate change or by nuclear accidents, affects the decisions and their outcomes. Private investors mostly adopt spatial and temporal perspectives excluding society wide events, but this does not guarantee they will be saved from the impacts. Public authorities (governments; the EU Commission) should assess the future with minimum spatial and temporal myopia and consider the full range of doubt from risk to ignorance. The assessments then find their way in enacted laws, directives and regulations that guide private decision makers towards the best decisions. Taleb (2010) advises to opt for robustness in hedging against ignorance.

Table 1. Three depths of doubt: risk, uncertainty and ignorance.

Depth of doubt	Events	Probabilities
Risk	X	X
Uncertainty	X	?
Ignorance	?	–

IRREVOCABILITY[2]

Third, irrevocability is an attribute of every decision as its definition "an irrevocable allocation of resources" (Matheson and Howard 1968) reveals. Verbruggen (2011) explores the widely used, but poorly defined, concept of irreversibility in economics, and shows that irrevocability is its economic constituent and comes in degrees. Practical use of the attribute irrevocability requires a workable metrics for gauging degrees of irrevocability. Workable metrics are based on reversal costs implied at a given moment in the future for undoing a previous decision. "Undoing" is considered feasible when accepting substitutability of all types of goods and values. This article deals with buildings made of substitutable materials and undoing a previous resource allocation is technically feasible, however costly it may be in reality.

Figure 2 shows three degrees of irrevocability as a function of how undoing costs develop over time: strong, medium, and weak, referring to conditions of preclusion, rigidity, and flexibility. The reference point for categorizing irrevocability is the initial (investment) cost at point 0 in time. Visual inspection of figure 2 shows that 'strong' irrevocability (preclusion) refers to reversal costs in the future that remain above the reference of the initial costs but decay over time due to depreciation of the

2. Irrevocability is systematically used instead of irreversibility, because a building is perfectly substitutable. For a detailed analysis, see Verbruggen (2010).

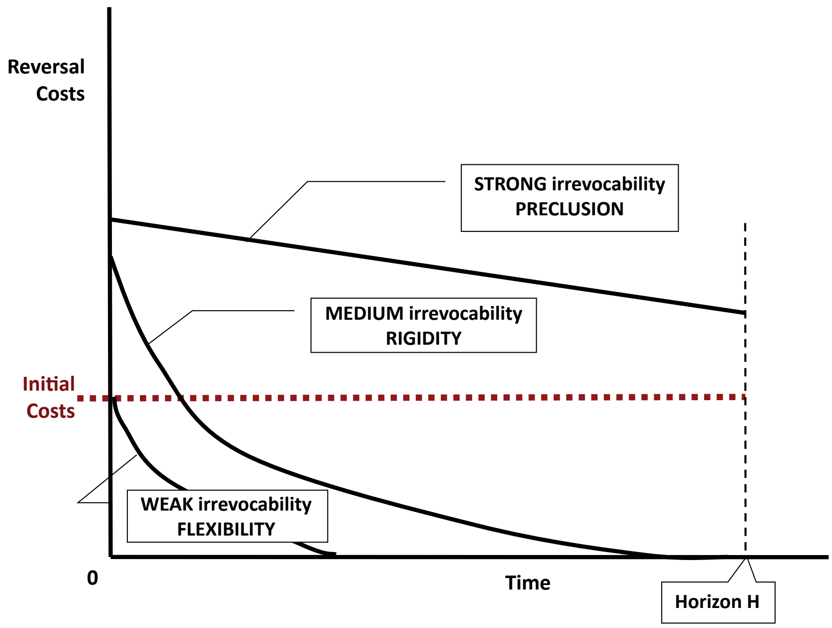

Figure 2. Reversal costs over time as metrics of irrevocability.

initial investments and to technological progress. For example, a basement underneath a house is a not so expensive space but it is precluded to construct it once the house is built.

'Medium' irrevocability (rigidity) refers to undoing costs higher than initial costs at moment zero and for some years, but falling below the initial costs later. For example when parts of a new construction have to be undone the value lost is not only the full price of initial placement but also the cost of demolishment and removal of the materials to recycling or dumping facilities. With time passing a construction is depreciated and the sunk costs decline.

'Weak' irrevocability (flexibility) is when the investment could be undone at a price equal or lower than the initial costs. For example, one can discard a piece of equipment without removal costs. With time passing depreciation further reduces incurred costs when one wants to undo the decision taken. With decommissioning a building, the issue of related irrevocability ends. When an investment can be undone at the initial cost price (for example by re-using a piece of equipment or selling it at the initial price paid or at its residual value during its depreciation lifetime), the decision is fully revocable at all time (the abscissa in figure 2).

Prevalence of categories of reversal costs and patterns of reversal cost curves depend on several variables, for instance: physical characteristics of the object, existence of markets for used equipment, technological innovation and economies of learning regarding possible substitutes in the future, etc.

What does "cost-optimal energy performance of buildings" mean?

In industrialized countries, almost 40 % of all commercial energy supplied as processed fuels and grid electricity is used in buildings (Laustsen 2008; EU 2010). The fourth assessment report by IPCC (2007) is very optimistic about the contribution of the buildings sector in reducing the emissions of carbon dioxide by energy efficiency. Also the EU sees the huge energy savings potentials, and the EPBD is the main instrument to unlock the potentials, while assigning a crucial role to the costing aspect. European energy efficiency policy bets most on regulation by standards, also when targeting the energy quality of buildings. The prescribed standards are derived from extensive physical and technical analysis of materials, building physics modeling, demonstration projects, statistical studies of the building stock, etc.

However, regulating "cost-optimal energy performance of buildings" should start from a clear definition of this target. Two parts in the goal definition ask for particular attention: "energy performance" and "cost optimal".

ENERGY PERFORMANCE ENDOWMENT OF BUILDINGS

The concept 'Energy Performance Endowment' (EPE) extends the EU Directive's 'energy performance' because it adds a focus on endowment. Endowment refers to a wide range of attributes (orientation, compactness, size, etc.) and items (components, equipment, etc.) that have an impact on the later energy use of the building. EPE is the incorporated capability (made up by attributes, structures, installations, equipment, etc.) of a building that largely determines energy use in delivering the functions wanted by the occupants. Later energy use or in other words, the actual energy performance, depends to a large degree on this endowment but also depends on a range of other variables that are not under control of the EPBD (or any other directive). The latter are factors like actual functional[3] use of the

3. Functional use refers on the one hand to the main function intended for the building (e.g., living, education, office work, health care), but on the other hand to the use intensity of provided capabilities of the building (e.g., number of actual occupants with time and duration of their occupation of the building, number of hot meals prepared in the building's kitchen, laundry – washing, drying, ironing – at home or processed externally, etc.). Regulations are or can be specific for intended functions, but cannot cover actual functional use (Verbruggen, 2008).

building, amount and quality of plug-in appliances, occupants' behavior, etc.

The endowment encompasses for example orientation, compactness, availability of passive construction parts (e.g. a cellar for cool storage), insulation and air tightness, shading blades, heat distribution equipment, coolers, sensors, meters, etc. One can equip a new building with an excellent, mediocre or poor energy endowment. Endowments are narrowly related to degrees of irrevocability, and need consideration during the planning phase (Laustsen 2008). Building regulations should focus on the endowment character of energy performance, which ultimately promotes and guarantees the best actual energy performance during later use of the excellently endowed buildings.

COST-OPTIMAL ENERGY PERFORMANCE ENDOWMENT

Experience teaches that a regulation is more successful, easier to implement, control, and enforce when prescribed rules and imposed standards correspond with financially beneficiary practices and with other pursued objectives held by the target constituency. Fixing performance standards requires economic and financial assessment of the benefits and costs they may imply. This explains the high interest the EPBD adheres to the cost aspects and to cost-optimality.

EPBD article 4 states: "Member States shall take the necessary measures to ensure that minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels", and: "A Member State shall not be required to set minimum energy performance requirements which are not cost-effective over the estimated economic lifecycle". The directive defines 'cost-optimal level' in article 2 (Definitions), as "the energy performance level which leads to the lowest cost during the estimated lifecycle". This definition only refers to the time dimension without attention for the other two crucial dimensions of uncertainty and irrevocability. The three dimensions taken together and the interactions between them determine what cost optimality means when investing in energy efficient buildings. The directive announces in article 5 "a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements".

A September 2010 report (BPIE 2010) seems a first step in that direction. The methodology presented for defining what cost-optimal means is however based on a static trade-off scheme used in textbooks to illustrate the impact of efficiency technology costs versus energy use bills. With such trade-off graphs teachers explain the impact of technological progress lowering the costs of efficiency technologies and the impact of higher energy use prices (for example through a levy on non-sustainable energy sources). Both measures together make the cup of the total costs roll towards a lower static optimal energy use. This comparative statics graph is a weak methodological basis for identifying the cost-optimal level of buildings' energy performance in the reality of the world characterized by technological innovation and accumulating climate change challenges. The added BPIE argument that the cost of overshooting energy use is as high as the cost of undershooting is not convincing builders to change habits and flip from one side to the other, as BPIE (2010, p. 16) wants to impose. BPIE (2010, p. 21) limits attention to irrevocability to a footnote on lock-in effects.

According the long-standing theory on investment it is necessary to consider irrevocability explicitly and process this aspect interactively with time and uncertainty for "avoiding very wrong answers that the traditional net present value rule can give" (Dixit and Pindyck 1994).

Instead of fleshing out the shortcomings of the BPIE proposals, this contribution tries to clarify what the recommended methodology is.

Dynamic people in a dynamic world

Theory and methodology testify improvement when they offer a better representation of reality. The reality of decision-making can grow complex and is dynamic when long time spans are covered.

A life cycle analysis considers the lifetime of a project, and discounting concentrates the history of the project during every year of that lifetime in summary statistics at the start of the project's life, like expected NPV (Net Present Value). Because the future is uncertain the analyst imagines future scenarios about the evolution of the major determining variables, and calculates NPV values for every scenario. This can be automated in Monte Carlo simulations offering nice graphs of the sensitivity of NPV for the various scenarios and their combinations.

The NPV or life cycle costing approach processes time in a professional way and sensitivity analysis informs about what variables have an expected major or minor impact. Its shortcomings lay in assuming the bundle of future scenarios as composed of once-through trajectories starting with investment (year 0) and ending with decommissioning (last year of the lifetime). This tunnel view does not reflect real life processes that actually are sequential, bifurcating and sometimes traversing, as we all know in looking back at our own life experience. The sequential character is modeled as an alternating flow of events – decisions – events – decisions – events[4], and so on. Decisions at a given moment in time are conditional on preceding events and decisions, and affect later decisions and the impact future events may have. When theory and methodology want to truly mimic reality the sequential process needs to be studied and modeled for future decision-making. Adopting sequential decision-making is critical for analyzing investments that span a long period (beyond 20 years), but is also appropriate and recommended for analyzing many shorter-term investments. Only the sequential analysis reveals the impact of irrevocability interrelated with time and doubt on the optimality of decisions. Sequential decision-making processes are graphed as decision trees (Raiffa 1970).

In the literature the sequential investment analysis (also named real option investment analysis) spends most attention to cases and circumstances leading to postponement (deferral) of the irrevocable allocation of resources (Arrow and Fisher 1974; Dixit and Pindyck 1994; Lind 1999). First, the standard framework of "Wait and Learn" is illustrated with a simple example. Then, I show that the case and circumstances of deciding on the energy performance endowment of buildings are the opposite of the standard and that the theory there leads to the situation of "Choose or Lose".

4. Events are out of control of given decision-makers, while decisions (also called strategies) are created by decision-makers or selected from a range of alternatives under control.

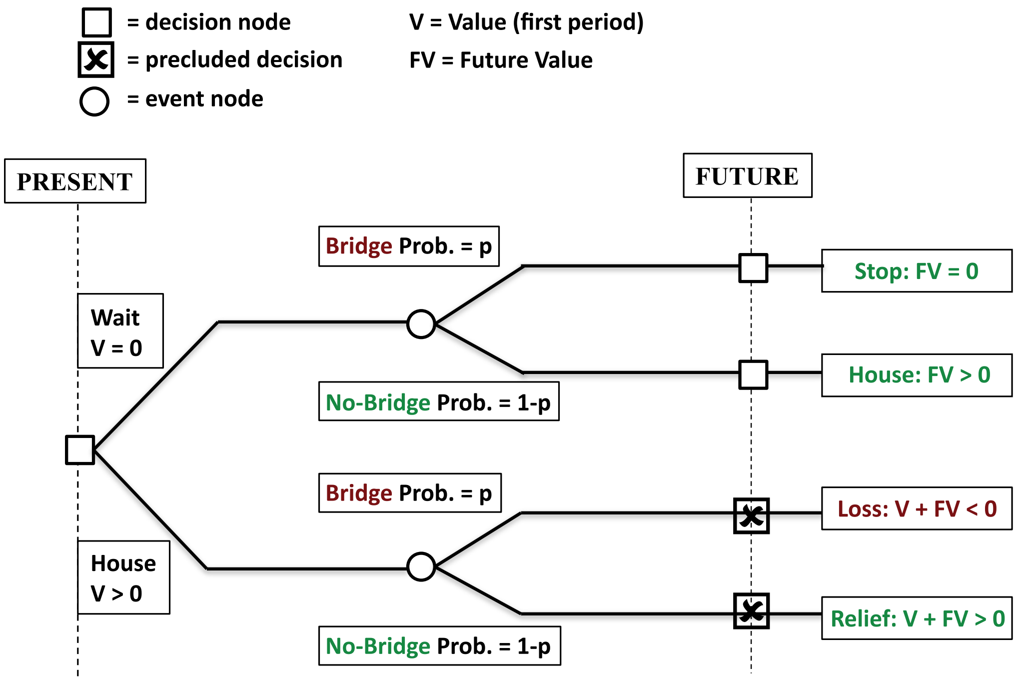

Figure 3. Sequential decision-making revealing "Wait and Learn" options.

IRREVOCABILITY SUPPORTS "WAIT AND LEARN" DECISIONS

Figure 3 shows the most basic decision tree covering two periods of decision moments (present and a moment in the future) with an intermediary stochastic event evolving (with only two possible outcomes: negative with probability p and positive with probability 1-p).

At the starting stage (mostly present time) a family may choose to wait or to build their own house. In principle, building at present only happens when the value V the house offers in the first period is assessed as positive (V>0). This is evident here because living in their own house, built according to the family's preferences, more benefits and amenities are expected than living in a rented house, with additional saving on rent paid. When for some reason one decides to wait, the first period positive value is foregone (V=0). When the house can be occupied in a quiet environment the future value (FV) is also positive; when the environment gets hectic FV<0.

In the years between present and future (e.g., a 5 year period) some uncertain events of high significance for the house building project may crystalise: assume for example the location of the real estate where the house is planned could be overspanned by a mega traffic bridge. At present there is doubt the bridge will be constructed between YES (probability p) or NO (probability 1-p). Placing yourself as decision-maker five years in the future, the best feasible actions will depend on the history that evolved up to that moment, and the decision made 5 years earlier will have a big impact. Four cases may happen:

- You waited to build, and the bridge hangs above your plot: you STOP the construction plan there (likely frustrated, but at least happy that you do not have to live for the rest of your life under continuous traffic flows; FV=0).
- You waited and the bridge project is definitely ditched: you can now BUILD your house (you have lost the V over the first 5 years, but this is the price of the option to decide with hands untied at this future moment; FV>0).
- You have built and the bridge and traffic are there above your roof (LOSS is your part; your investment is almost worthless and you have spent your credit so you cannot move: V+FV<0).
- You have built and the bridge project is definitely ditched (RELIEF is yours; you already enjoyed the value V during 5 years, and you can continue to live quietly on the plot you wanted: V+FV>0).

Which decision (Wait or Build) is best at the start of this process depends on the actual values of V, FV (negative and positive) and the probabilities p and 1-p. But only the sequential layout of the decision process makes apparent the option of "Wait and Learn". That sequential option is obscured when sticking to the easier static approach of expected life cycle values. The necessity to perform a careful sequential decision analysis grows with the degree of irrevocability that characterizes particular investments.

IRREVOCABILITY SUPPORTS "CHOOSE OR LOSE" DECISIONS

The decision analysis literature is heavily loaded with "wait and learn" arguments and cases, for example Dixit and Pindyck (1994), Lind (1999), Manne and Richels (1991), Kolstad (1996). A few authors have pointed to this imbalance and suggested that also the inverse cases need attention (Grubb 1997; Fisher 2001; Webster 2002) because if one does not develop alternatives in time one may be locked in old pathways for too long if not forever. Lock-in may also occur in the development of efficiency and renewable energy technologies as a substitute for non-sustainable energy supplies. For buildings, lock-in is magnified because of the long lifetime and the irrevocability of major components and connected attributes of buildings.

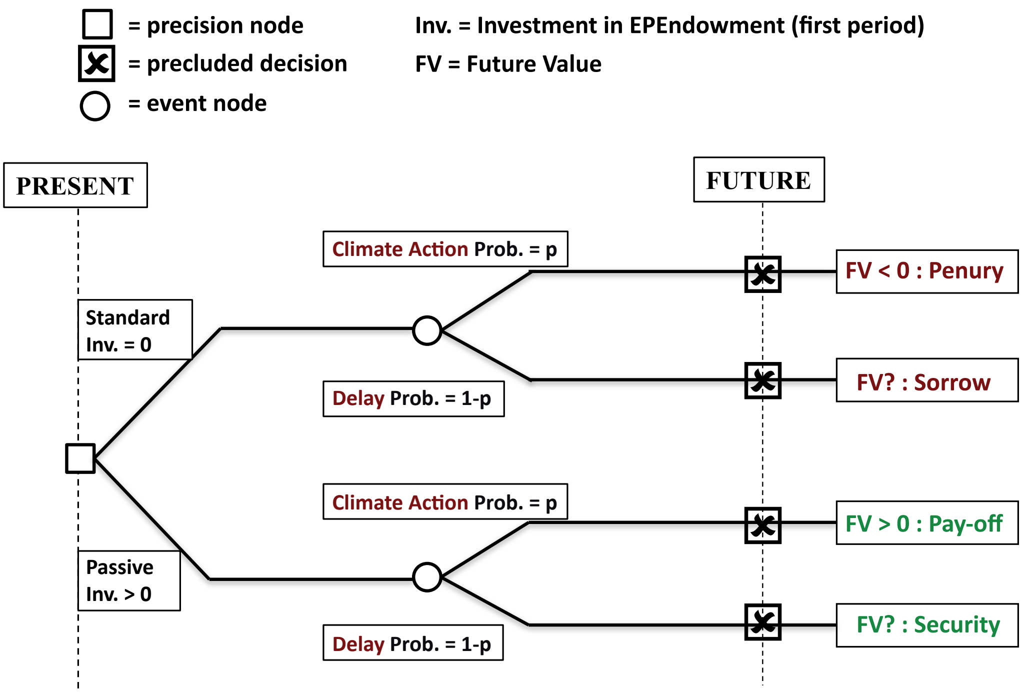

Figure 4. Sequential decision-making revealing "Choose or Lose" options.

Constructing a building implies a large number of decisions, with some being related or conditional, others being independent. At the outset, it is important to clarify the distinction between physical and economic irrevocability: a building is physically an irrevocable investment but a liquid one economically when there is a lively real estate market (selling/buying; letting/renting). When a decision-maker avoided irrevocability funnels like a bad location illustrated above, weak or medium irrevocability apply on the largest share of building investments.

However, several parts of a building are tied to the construction and characterized by strong irrevocability, in particular this is true for most energy performance items. At the planning and design phase, the Energy Performance Endowment (EPE) of a building is decided. The literature pays little attention to distinguishing between the building as such and its EPE, because both are highly interwoven. For example, the custom is to label houses as a whole on their energy efficiency merits, although precise delineations are difficult on what components and attributes distinguish standard houses (meeting the imposed energy standards, expressing the EPE level considered as optimum by regulators), low energy houses, passive houses, net zero energy, and energy producing houses (Sartori et al. 2007; ECEEE 2009). Therefore numbered energy consumption levels per m^2 are used as a substitute, which is not very precise because of the wide range in functional performance of buildings within the same category.

Buildings differ in initial EPE at construction. A new building holds many degrees of freedom in EPE optimization. Several important features that make a construction passive belong to the strong irrevocability or preclusion class (figure 2): costs to adapt the attribute or add the item after finishing the construction are higher than costs of realization during construction and remain higher (mostly prohibitive) during the building's lifetime. Examples are; building orientation, size and type; slope, orientation, and overarching of roofs; insulation quality and quantity; air tightness; rainwater collection and storage; position, size and thermal integrity of windows and doors; floor space layout; pipes; ducts; the provision of cellars (basements), etc. The attribute of being passive or not is part of the energy performance endowment that only can be decided at the design table. The decision on the EPE cannot be delayed[5], excluding the option "Wait and learn". Under Dixit-Pindyck (1994) conditions more irrevocability strengthens the wait option. In the EPE case the thrust is opposite: more irrevocability stimulates us to choose now for the most irrevocable EPE attributes and items in order to avoid preclusion of efficiency solutions in the future. This is illustrated in figure 4 (like figure 3 a binary choice, two-period example).

An investor can at present choose between a standard and a passive building, more precisely between a building with a standard EPE and a building with a passive EPE. This choice is highly irrevocable, and once taken future performance and decisions are characterized by preclusion: changing the EPE of the building is ruled out in advance. The following events are considered: either the reversal in present climate policy towards firm "climate action" (probability p), or the continuation of climate policy delay (probability 1-p). The four possible future states are:

- Standard EPE and Climate Action: the future value is highly negative and the owner will experience PENURY.

5. It may be understood that the standard option theory as described in section 3.3 and in Dixit and Pindyck (1994), also can be applied to find the optimum date for starting the construction as such, a timing also influenced by EPE choice opportunities. However, many other (for people more important) considerations will fix the date of constructing, and therefore analytical separation of the two decisions is plausible.

- Standard EPE and Delay: the nearby FV is fine, but the longer term FV remains uncertain because climate change is increasing; the owner is left in a situation of SORROW.
- Passive EPE and Climate Action: the initial extra investment Inv.>0 is paid, but the energy savings in the coming years (FV>0) brings a good PAY-OFF for the owner.
- Passive EPE and Delay: the extra Inv.>0 is spent and there is no immediate high return for it. The future value FV remains uncertain, but SECURITY for energy price rise is obtained.

When the probability of climate change and therefore climate action passes some low threshold and the EPE investment is not prohibitively large (as most empirical evidence confirms) it is recommended to invest in passive EPE. Applying decision analysis leads to "Choose or Lose" (provide now to avoid preclusion), opposite to the common "Wait and Learn" (defer the irrevocable investment and keep the option to decide later). The irrevocability characteristics of EPE stimulate immediate very efficient (passive) buildings rather than standard obeying buildings. The latter are mostly advised on the basis of traditional net present values or life-cycle costing that in this setting "may give very wrong answers" (Dixit and Pindyck 1994).

The good as worst enemy of the best

Three dimensions – time, uncertainty, and irrevocability – in decisions on the Energy Performance Endowment (EPE) attributes and items of buildings are discussed. The importance of time sequential decision analysis and of irrevocability is argued. Application of concepts and tools of the decision-making literature on investing in the energy performance endowment of buildings induces new insights and more appropriate concepts. For measuring the degrees of irrevocability a classification in strong (preclusion), medium (rigidity) and weak (flexibility) is developed. Timing of EPE decisions is locked to the building's design/construction year, and the "Choose or Lose" option substitutes for the standard "Wait and Learn" advice.

The purpose of the article is didactic, but the methodology also entails highly relevant lessons for practical decision-making and regulatory policy.

First, energy performance of buildings requires a focus on the endowment character of many components and attributes that are decisive for later energy efficiency of the building. Therefore preference for the concept Energy Performance *Endowment* is warranted.

Second, the definitions and methods to find the cost-optimal levels of EPE should be based on proper science and investment appraisal theory. This includes the consideration of the dynamics of sequential decisions with irrevocability in its various degrees. The EPBD (EU 2010) and the first report of the BDEI (2010) stick to textbook trade-off schemes and limited lifecycle costing.

Third, the methodological stalemate is of high policy importance. Using scientifically correct and comprehensive regulations will provide investors with incentives to choose immediately the most passive EPE approach. The limited scope of lifecycle costing will come with middle-of-the-road expected values that preclude high-efficient performance in the future.

Fourth, when opening our eyes for upcoming climate change events and effects, it seems utterly important to avoid preclusions in the EPE of houses and of any other building. It makes sense to choose the highest quality EPE when designing a building in order to avoid losing flexibility and resilience in the coming years.

Fifth, the focus on investment appraisal methodology has sidelined the significant amenities and positive externalities that high-quality energy performance offers the occupants of buildings and society at large. Also this account should be established in full size and in all clarity. It will only strengthen the push to high energy performance endowments of buildings.

By now the title of this article has lost its mystery: the good can indeed be the worst enemy of the best. And for addressing climate change only the best energy efficiency is acceptable.

References

Arrow, K.J., Fisher, A.C., 1974. Environmental Preservation, Uncertainty, and Irreversibility. Quarterly Journal of Economics 88, 312–319

Bierman, H., Bonini, C.P., Hausman, W.H., 1977. Quantitative Analysis for Business Decisions. Richard D. Irwin

Bierman, H., Smidt, S., 1971. The Capital Budgeting Decision. The Macmillan Cy.

BPIE, 2010. Cost Optimality. Discussing methodology and challenges within the recast Energy Performance of Buildings Directive. The Buildings Performance Institute Europe, Brussels. www.bpie.eu

Dixit, A.K., Pindyck, R.S., 1994. Investment under Uncertainty. Princeton University Press. Princeton, New Jersey

ECEEE, 2009. Net zero energy buildings: definitions, issues and experience. European Council for an Energy Efficient Economy, Stockholm. www.eceee.org

EU, 2010. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. Official Journal of the European Union 18.6.2010 L153/13–35

Fisher, A.C., 2001. Uncertainty, Irreversibility, and the Timing of Climate Policy. Conference on the "Timing of Climate Change Policies", Pew Center on Global Climate Change.

Grubb, M., 1997. Technologies, energy systems and the timing of CO2 emissions abatement. Energy Policy 25 (2), 159–172

IPCC, 2007. Climate Change 2007. Fourth Assessment Report. Working Group III Report "Mitigation of Climate Change". Cambridge University Press. Online available at www.ipcc.ch

Jelen, F.C., Black, J.H., 1983. Cost and Optimization Engineering. McGraw-Hill Book Cy.

Kolstad, C.D., 1996. Fundamental irreversibilities in stock externalities. Journal of Public Economics 60, 221–233

Laustsen, J., 2008. Energy Efficiency Requirements in Building Codes, Energy Efficiency Policies for New Buildings. IEA Information Paper. International Energy Agency, Paris.

Layard, R., ed. Cost-Benefit Analysis. Pinguin Modern Economics Readings. Pinguin Books Ltd, England.

Lind, R.C., 1999. Analysis for Intergenerational Decision-making, p. 173–180, in Portney and Weyant eds. Dis-

counting and Intergenerational Equity. Resources for the Future, Washington, DC
Manne, A.S., Richels, R.G., 1991. Buying greenhouse insurance. Energy Policy July/August, 53–62
Manson, N.A., 2007. The concept of irreversibility: its use in the sustainable development and precautionary principle literatures. The Electronic Journal of Sustainable Development 1 (1), 3–15
Matheson, J.E., Howard, R.A., 1968. An Introduction to Decision Analysis. Stanford Research Institute.
Munasinghe, M., Meier, P., Hoel, M., Hong, S.W., Aaheim, A., 1995. Applicability of Techniques of Cost-Benefit Analysis to Climate Change. In IPCC "Climate Change 1995. Economic and Social Dimensions of Climate Change.", pp. 145–177
Portney, P.R., Weyant, J.P., eds. 1999. Discounting and Intergenerational Equity. Resources for the Future, Washington, DC
Raiffa, H., 1970. Decision Analysis. Introductory Lectures on Choices under Uncertainty. Addison-Wesley, Reading, MA.
Rushing, A., Lippiatt, B., 2008. Energy price indices and discount factors for life-cycle cost analysis. National Institute of Standards and Technology, U.S. Department of Commerce.
Sartori, I., Hestnes, A.G., 2007. Energy use in the life cycle of conventional and low-energy buildings: A review article. Energy and Buildings 39, 249–257.
Stirling, A., 1999. On science and precaution in the management of technological risk. SPRU, University of Sussex.
Taleb, N.N., 2010. The Black Swan: The Impact of the Highly Improbable. Random House, USA.
Verbruggen, A., 2008. Reftrofit of a century old land-house to a low-energy house. International Journal Environmental Technology and Management 9(4), 402–412
Verbruggen, A., 2011. Revisiting Irreversibility: concepts and metrics. University of Antwerp, mimeo, submitted for presentation at EAERE conference (Rome, June-July 2011).
Webster, M., 2002. The Curious Role of "Learning" in Climate Policy: Should We Wait for More Data? The Energy Journal, Vol.23, No.2, 97–119

Acronyms

CBA = Cost-Benefit Analysis
EPBD = Energy Performance of Buildings Directive (2010/31/EU)
EPE = Energy Performance Endowment
NPV = Net Present Value