Degrees of Freedom in Information Sharing on a Greener and Smarter Grid

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ABSTRACT - Providing warmth, food, housing, and other necessities of life require the use of energy, which causes it to play a pivotal role in society. Changes in the production, distribution and consumption of energy (carriers) impact everyone. Next to well known (expected) changes in the area of renewable energy sources, we foresee the possibility of major changes in the way society shares information about production, distribution and consumption of energy (carriers). This is caused by the expected societal benefits of exchanging more information between parties connected on the energy grid: more efficiency though balancing of supply and demand, which in turn makes energy less scarce and avoids unnecessary 'heat pollution'. However, the sharing of information could introduce imbalances in 'societal' power between governments, companies and consumers. We argue that all parties involved should consciously decide – on a well informed basis - on what information they want to share. In this paper, we provide an overview of the degrees of freedom in information sharing on the green & smart energy grid of tomorrow.

Keywords – Smart grid; information sharing; privacy.

I. INTRODUCTION: RISE OF THE 'ENERGY INTERNET' DEMANDS INFORMATION SHARING

In the coming years, we expect a further development of the 'Energy Internet'. Classic energy grids (electricity, gas, heat, etc.) will evolve into an even larger combined world wide network which will be used by millions of parties to exchange both energy itself as well as information about the production and consumption of energy carriers (oil, gas, electricity, etc.). The Energy Internet is the next step in evolution of the classic 'Energy Grid', which today consists of electricity cables, transformers, pressurizing stations, gas pipes, etc. and is often characterized by a unidirectional flow. Electricity and gas flow from central power plants and gas production facilities, towards companies and consumer houses. The rise of decentralized production of energy carriers – for example: solar panels, windmills, biogas installations, etc. – will result in a more bidirectional flow of energy carriers. Consumers' houses and other decentralized facilities like farms will not only consume energy carriers but will sometimes also produce energy carriers to such an extent it is economically or environmentally interesting to transport the energy to other sites. In the Netherlands, for example, this is already the case in the 'green house industry'. The production of heat from gas is often combined with the simultaneous production of electricity. 'Surplus energy' from green houses is carried – using electricity - across the classic energy grid by so called 'Network Administrator' companies to other parties that have a need for this energy.

Next to the physical evolution, on top of the classic grid a new information sharing network will evolve. This network will be used to exchange information on many aspects of the (expected) production, storage, transportation and consumption of energy carriers (see [8], [9] and [11] for examples of information services and architectures). Another advanced example is the application of automated (i.e., computerized) trading agents that use real-time information to buy and sell energy according to a buy/sell strategy of their owners/parties they represent. To that, these agents could be equipped with the ability to switch energy carrier consuming equipment on or off, depending on the availability and price/costs of energy. Pricing strategies and regulations (set by governments) could influence buying and selling behaviour. This information exchange could take place on different levels: between individual houses in a residential area and factories, between groups of consumers and producers, etc. It is beyond the scope of this paper to describe the possible implementations of a more automated and dynamical market where real-time information is used to synchronize demand and supply. In this paper, we want to focus on how to categorize why, what kind of information and when it is exchanged. We have chosen to focus on exposure of behaviour and identity of parties on a Smart Grid. Also it is beyond scope to discuss the effects of local energy production and consumption on network stability.

In Section II, an overview of the related research is given. After that, our contribution and methodology is presented. In Section IV, we present the three degrees of freedom. Followed by, the consequences of the possible choices. In the end, we will present our conclusions.

II. RELATED RESEARCH

We found abundant research related to the concept of *using* information to create a greener and/or smarter energy grid. Potter [4], for example, recognizes the importance of information on the smart grid. He claims that the variation on renewable energy sources will be the largest variation on the smart grid. As a result – as we paraphrase it - better procedures are needed to forecast the weather in order to provide a better estimation the energy production from renewable energy sources. Potter focuses on the accuracy of the information on production of energy carriers from

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renewable energy sources in order to optimize (smart) grid efficiency. Little attention is paid in this article to aspects of sharing information on energy usage between parties connected to the grid (e.g., factories, consumer households, etc.).

Another example of the usage of (extra) information for a smart grid was found in a pilot study called – 'PowerMatchingCity' [2] of the European 6th framework project INTEGRAL (Integrated ICT-platform based Distributed Control in Electricity Grids). In this pilot, the so called Powermatcher Smart Grid Technology [1] was used. It is built on a market based control concept in which each device attached to the grid produces bids on energy, and a central market where the offers and bids are matched to each other. Information between parties is exchanged as 'prices' and 'bids'. Suppliers offer 'energy' together with prices, while consumers bid on those offers. Through an auctioning mechanism the 'PowerMatching' system as a whole tries to find a market equilibrium where net balance is optimized [3]. A conceptually related example is Intelligent Metering/Trading/Billing System (ITMBS) as described in [10]

III. Our contribution & methodology

While we found an abundant research relating to the topic of using the information, research on the *type* of information and *reasons* or *objections* to share information on energy usage seems scarce [12]. We did find several projects and studies which developed their own information sharing model and we found it hard to compare the different models. Such a comparison is needed when a decision has to be made about an information sharing model; which has been the case in the Netherlands for example, where amongst others stakeholders politicians have been discussing the introduction of the Smart Meter. In that discussion questions arose like:

- What information should be shared?
- How much detail should be provided?
- Who can access the information?
- What is the impact of (not) sharing all information?

Our contribution is a structured model to compare information sharing on different (partial) Smart Grid designs and implementations, with a strong focus on the level of transparency (of behavior and identity) between parties on the Smart Grid. As a result, comparison should be less hard and more effective. This enables decision makers to come up with a substantiated choice more efficiently. We have named the proposed model 'Degrees Of Freedom in Information Sharing' (DOFIS) for Smart Grids (4SG), resulting in the DOFIS-4SG acronym.

The basic structure of the model is a set of axes, because we wanted to be able to carry out a comparison, between Smart Grid designs, in terms of different aspects. Each axis is a 'degree of freedom' and represents an aspect of information sharing with respect to *exposing* behavior or the identity of the owner or 'generator' of the information. This means not all aspects of information sharing are included. For example aspects like the size and structure of information are not included, since these aspects hardly reveal any information about the behavior of a party on the energy grid at all. The aspects of information sharing we did include are related to revealing behavior and identity. The basis for the included aspects was found in literature on Smart Grids and we tried to distill the greatest common denominators and make additions where they were necessary in order to provide for making comparisons. The process of distilling common denominators and making additions was supported by our experience with both information architectures for Smart Grids on which we are currently working and on our experience with information architectures in other domains where large scale information sharing takes place (telecommunications, healthcare, road pricing). This means that we did not mathematically derive these aspects, but carried out a selection process based on the criteria 1) 'relevant to exposing behavior and identity' and 2) the axes being 'orthogonal'. This means that the location on one axis cannot be derived from a combination of locations on the other axes. Compare this to a classic x,y,z 3D grid for describing the location of points in a 3D space: the z part of a coordinate cannot be deduced from the x and y part.

The process of distillation and selection above has resulted in what we call a 'space of comparison' which *currently* has three axes. Currently, we *suspect* that these axes and their subdivisions can be used to assess and compare all aspects of information sharing with respect to exposure of behavior and identity of parties on a Smart Grid. Providing proof for this should included in further research.

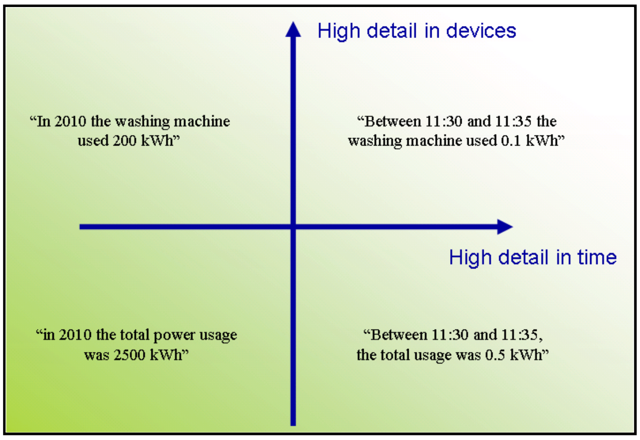

Figure 1. Different levels of detail in energy consumption information

Note that in this version of our model we use a simple view on energy systems/markets, where consumers are sharing information with each other, and with the producers of energy carriers. Business roles like retailers and distributors which are present in several market models are not mentioned explicitly. However, the sharing of

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information between business roles like retailers and distributors can also be positioned using the DOFIS-4G model. Instead of consuming energy carriers directly, they consume energy carriers indirectly by reselling or distributing it to their customers.

IV. DEGREES OF FREEDOM

In this section we present the axes of our DOFIS-4SG model. All axes together constitute the model. In the next Section we will use this model to identify possible shifts in power (by information) between parties connected to (smart) energy grids.

A. *Level of Detail (LoD)*

The first axis we present is about the Level of Detail (LoD) of information. The LoD strongly influences what kind of market-models and types of energy matching & distribution are possible. For example, when a consumer shares its total usage of energy once a year, the receiving party can use this for constructing a yearly bill. However, when information is shared on an hourly basis, it becomes possible for the receiver to bill by the hour, and thus, it influences the consumption of energy by financial incentives. We identify two different types of LoD:

- **Devices.** To which extent is information shared about the energy usage of separate devices? For example, in the Netherlands in most houses only the total accumulated usage of electricity by all devices 'behind' the electricity meter is shared with the power supply company. However, information could also be shared on what device consume(s/d) the electricity. The energy supplier could use this information to understand which devices make up for what amount of the total power usage at a house.

- **Time.** To which extent is information shared about the energy usage over time. For example, instead of sharing information about the electricity use of once a year, it is also possible to share information more or less often.

In Figure 1, an overview is given of the two LoD types and how they congregate. Both axes represent one of the detail levels, and together they span a field of possible choices.

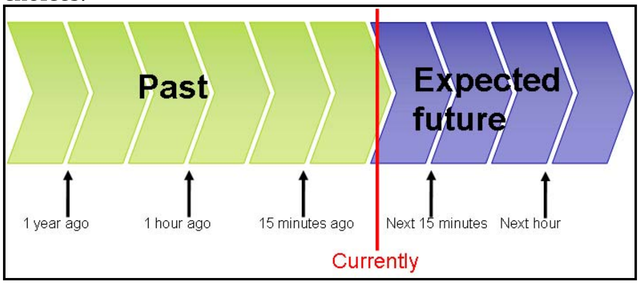

Figure 2. Information about the past, current and future

B. *Direction in Time (DiT)*

Next to the LoD, we consider the direction in time as another degree of freedom with respect to information sharing. There are three different points in time to share information:

- **Past.** Information on the usage of energy that has taken place in the past. Two examples about energy usage (e.g., power consumption) in the past that are often shared. The used amount of energy in a certain period (e.g., kWh) and the consumed amount of energy on a certain moment (e.g., Watt). In the current situation on the energy grid in the Netherlands, many consumers share their total power consumption in the past with their energy supplier once a year.

- **Current.** Information on the current speed at which energy is flowing. An example is the current power consumption (Watt). Note that it is theoretically impossible to share information about the absolute current use instantaneously.

- **Future.** Information on the estimated usage of energy that will take place in the future.

In Figure 2, a timeline is presented that shows the three points/periods in time.

C. *Recipients*

The third degree of freedom is about the amount and type of recipients of information on energy usage. For example, there is a huge difference between sending information to only one trusted party or to a group of parties which might send this information to even other parties.

In generally, the more recipients, the more the privacy of the consumer is violated. However, not only the amount of recipients is important, the type of recipient is important to. For example, there is a difference between sending information the energy supplier, or sending information to a neighbor.

V. CHOICES HAVE CONSEQUENCES

Now, as we have presented a model with (three) degrees of freedom, we can compare market models and energy systems with *respect to consequences*. In this Section, we will provide the reader with several examples in different areas that show the consequences of making different choices in information sharing. In other words: a different position in the DOFIS-4SG set of axes means different consequences. For example, certain services and market models preclude certain levels of privacy. We have identified four categories of consequences and we will use those to present the examples in a structured way. As an illustration of the consequences, we introduce two possible future energy systems/markets in which electrical energy will be exchanged/sold. Both energy systems are extreme, and it is not likely that only one of them will be put into practice. We

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expect something in the middle. However, their location at opposite sides of the spectrum is useful to illustrate the consequences of information sharing decisions. The examples will show that choices (i.e., restrictions) on information sharing can enable or disable certain energy systems and markets. The two ‘opposites’ are:

- **“Massif Central”.** In this scenario, governments and electricity supplying companies will invest their money in extra centralized energy production capacity. As a result the current energy grid will need to be scaled up, to be able to handle the peak loads in areas where electrification is increasing (in some areas of the Netherlands heating by gas is changing to heating by electricity using heat pumps). Thus, in the Massif Central scenario there seems to be little need for producers and consumers of energy carriers to share information. There is a relatively small need for ‘real-time’ control/coordination systems to manage the transport of energy (carriers), since there is relatively little to coordinate due to centralized power plants. This requires less agreement between parties on the Energy Internet. Thus far less information sharing is needed. Within the model it can be positioned as having A) a low Level of Detail with respect to time and devices, B) little to zero need for sharing information about the current and future and C) very few recipients (only electricity supplier) needed.

- **“Distributed Load”.** This scenario is the opposite of the ”Massif Central” scenario. Money is invested in a smart grid which will match production and consumption for efficiency and also to decrease peak loads on the network. Electricity from renewable sources (solar, wind) with a dynamical and relatively unpredictable behavior is allowed on a massive scale on the grid. To match production and consumption, there is functionality embedded in the Smart Grid to automatically switch devices like washing machines on and off, based on offerings of energy. As a result there is a greater need for producers and consumers of energy carriers to share information. Many different parties have to agree upon the amount of energy (carriers) that they will use at a certain time. Depending on the exact type of implementation, information about (household) appliances like washing machines might even be shared. Within the model this energy system/market can be positioned as having A) a high Level of Detail with respect to time and devices, B) need for sharing information about the current and future and C) a relatively larger group of recipients needed.

Note that the two example energy systems/markets are very roughly positioned. This is due to the fact that the two examples are roughly described because of reasons of space. The main purpose of these examples is to show that the model allows for comparison. Also note that we have not described all parties involved in detail.

With these two differently positioned example energy markets/systems in mind, we can provide the different categories.

A. Consequences for production, distribution and net-balance

The expected energy usage and production information is needed by intelligent distributed control algorithms to increase both efficiency and net-balance (e.g., see [13]). The overview in Table I shows that the choices with respect to the type and amount of information which is shared have consequences for the ability to arrive at one of the two energy systems described above. For example, without sharing any information on expected consumption, it is very difficult to arrive at a stable balance in a heavily distributed load situation with a significant amount of intermittent (renewable) energy sources.

TABLE I.
SHARING OF INFORMATION IN DIFFERENT SCENARIO’S

	”Massif Central”	**“Distributed Load”**
Level of detail of consuming devices	Information sharing is not necessary	Information sharing per device, in order to switch devices on/off, in order to balance the grid.
Level of detail in time	Information sharing is not necessary	High level of detail required, in order to switch devices on/off in real time.
Direction in time	Information sharing is not necessary	Information about the expected future needed, in order to optimize decisions about which device should be switched on/off
Recipients	Information sharing is not necessary	Information needs to be shared with several parties. Which ones, depends on where the intelligence is located within the Energy Internet.

B. Consequences for financial settlement

Financial settlement between consumers and producers of energy carriers requires information from a trustworthy source on the amount, date, time, etc. of energy (carriers) used, depending on the financial agreements between consumer and producer. For example, in the Netherlands, it is customary that consumers share information on their total energy carrier consumption (electricity and gas) each year with their power supplier. Since this is an accumulation – i.e., total kilowatt-hours of electricity and total cubic meters of gas – little can be deducted on the actual pattern of use of the consumer. Charging a customer for actual use at a daily

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or monthly basis is not possible, due to the yearly accumulated exchange of information. Also, billing by the hour is not possible. If the producer would like to offer 'hourly prices', this means that there should be a log 'per hour'.

In one of our research projects at TNO, we are studying the necessity and effect of stimulating flexibility in energy usage by using financial incentives. For example, consumers could (indirectly) offer 'flextime' to producers. The idea here is that household appliances like washing machines are switched on if it is beneficial for the greener/smarter grid as a whole to do so. A consumer provides a 'flex offer' to the grid (how is beyond of the scope of this article) where it states that somewhere in next hours the washing machine should be turned on. The longer this period in time (i.e., the more flexibility), the higher the financial compensation the consumer gets, because the consumer is helping the greener/smarter grid to achieve its efficiency goals. This is only possible if the consumer is willing to share information with its energy supplier on when he/she expects or wants to use a certain amount of power. Note that it is also possible to share less detailed information with an energy supplier, by first accumulating that information in a group (e.g., a neighbourhood) and share the accumulated information. In this way, the producer has no information about the consumption of each separate home, but only the aggregate information of the entire neighbourhood. However, the financial compensation should probably go to this group. And within this group, the compensation should be divided again.

We do not elaborate on different financial compensation schemes in this article, neither do we elaborate on other possible incentives (e.g., see [7]): our point is that in order to provide a possible incentive, some degree of information sharing is required. We provide two example goals of a greener/smarter grid that might be achieved by using financial incentives. Those two examples are given in Table II. Note that these are 'imaginary' examples. Current legislation determines whether this is possible in today's energy market. Also note that the two example goals and incentives might also be used to improve network management (see next category of consequences), because their possible influence on the consumption of energy might result in less unwanted peaks for examples.

TABLE II.

CONSEQUENCES FOR BILLING

Goal	Required information level
Decrease total volume in a year	Relatively less detailed information is needed. Can be deduced from a meter with a 'running total', which is 'read' by a computer or humans once a year. No intermediate measurements are needed.
Decrease used volume in a certain period during a day	Relatively more detailed information might be needed. If periods are fixed (i.e., day and night) and energy prices remain the same during that period of the day for a year, then a meter with a 'running total' per period can be used; which are read at the end of each year. The more separate periods in a day, the more meters. If energy prices differ on a day to day basis, the meter should be read every day. If periods are not fixed, a meter with a running total per period does no longer suffice. Instead, the meter should be read at the beginning and the end of a period, and this information should be shared with the energy supplier.

Note that it is not (always) necessary to send measurement information to the transport or energy provider in order to provide the consumer with a bill. When information for 'pricing' is available 'on site' (i.e., next to the measurement device) the total amount of money to be paid in a certain period, could be calculated on site (in a special intelligent device next to the meter) at the consumer site. This requires that information on (actual) prices for energy (carriers) in a certain period needs to be sent to this device. Connectivity with energy transporting and measurement parties are needed. Note that in order for the total amount of money to be trusted by all parties, there are demands to the device carrying out the measurement and pricing, since the ability to change 'measurement data' or 'pricing information' on site within the device would enables the consumer to commit fraud. Vice versa, the consumer might not trust the provider/transporter of energy carriers if it cannot see measurement and pricing information. Measurement and pricing should therefore probably take place in a 'sealed environment' [6].

C. Consequences for network-management

Many different parties will connect to the Energy Internet of the future. This will be parties like: houses, factories, farms and hospitals. They use the energy infrastructure to receive energy carriers like electricity and gas. Also, in the future, they will send energy carriers. For example, houses with solar panels might produce electric power and farms might deliver biogas, just like green house companies with industrial strength Combined Heat & Power (CHP) equipment supply electric power. The classic asymmetry in power flow will disappear and more symmetry will evolve. Traditional models of the use of networks for energy carriers do no longer suffice. This impedes network management organizations in carrying out network capacity planning, maintenance, etc. In order to retain insight into the workings of the energy carrier transportation networks (as well as providing net balance, information about the (estimated) flow of energy carriers is needed. Currently, we suspect that more sharing of information between network management related parties on the grid is needed, but we cannot state yet which positions in the DOFIS-4SG preclude proper network management (in general) on a Smart Grid. The According to us, this is still a research topic.

D. Consequences for privacy and balance of power

Sharing information about energy (carrier) usage means sharing information about the behavior of (a collective of) machines (in houses/factories) and indirectly sharing information about company information (e.g., amount of products produced) or personal behavior. For example: a graph that shows the accumulated electrical power and/or gas consumption of a house through time – every minute - provides insight into activities of the residents; the presence of people is reflected in the usage of energy: with some basic knowledge of energy consumption patterns it is often possible to deduce the use of washing machines, televisions, etc. from such a graph [5]. If even more detailed information is shared – like a graph per household appliances– then very little knowledge is needed to deduce information about a person's life from his energy carrier consumption. For example, how early does a person get out of bed, when does he/she go to work, how often does he/she use the washing machine, etc. In short: sharing of information is a potential violation of privacy. In Table III, we show how the degrees of freedom are related to privacy.

TABLE III.

IMPACT ON PRIVACY

Degree of Freedom	Impact on privacy
More Level of Detail	An increase in the breakdown of accumulated information into detailed information (e.g., at the appliance level), means less privacy with respect to the consumer of energy carriers.
Direction in time	Information about the future provides insight into predicted or expected consumption of energy carriers and removes the ability for consuming parties to keep their future energy consumption private. The same applies to information about the current and the past. There is a potential privacy violation.
More Recipients	An increase in the amount of recipients means less privacy. Note that the type of recipients also matters. We expect that most consumers will not object to their energy provider receiving information, while most consumers will object to sending it to their next-door neighbors.

Closely related to the concept of privacy is the concept of the 'balance of power by information'. In general this concept is about the ability to exercise (a certain amount of) power by the recipient of energy usage information on the sender. For example, if information about predicted energy consumption somehow becomes available to criminals, they could decide to 'visit' a certain house when predicted energy consumption is at a minimum, since this is an indication of the inhabitants of the house be absent. Also, government agencies could decide to use that information for tracking down people involved in social security fraud. The amount of electricity used at a location provides information on whether or not – or how many - people actually inhabit a residence. This shifts the balance of power in the direction of the state and away from its citizens. Another example is the public availability of power consumption of factories: market analysts could use this information for estimates on production numbers. A final example is where (commercial) parties target certain consumers for new washing machine offers based on their power use signature.

In short: sharing information potentially shifts the balance of power by information. By sharing information with another party, that party is empowered in some way. More information could lead to more power (by information) and more power could mean the ability to collect even more information.

VI. CONCLUSIONS

In this paper, we have shown that the evolution of classic energy grids towards the future Energy Internet will have impact on information sharing between parties connected to the grids. In order to meet the growing demands for more sustainability (i.e., a greener grid) and more efficiency (i.e., a smarter grid) there is a need for change in information sharing. To evolve towards a greener grid, there seems to be a need for the increased use of decentralized intermittent energy sources (wind, waves, solar, etc.). This in turn seems to require more coordination between producing and consuming parties on the grid, just as is needed for a smarter grid. More coordination requires sharing more information, which in turn will have impact on privacy and balance of power. Also, the use of financial incentives to stimulate certain behavior with respect to energy carrier production and consumption (e.g., time and volume), will also require more information to be shared on the actual production and consumption patterns. Deciding upfront not to share this information because of privacy reasons means disabling several ways to evolve to a greener and smarter grid. This leads us to our final conclusion that for the evolution to a greener and smarter Energy Internet to take place it is important to put information sharing mechanisms into place, that stimulate sharing, provide as much privacy protection as possible and finally enable society to consciously decide on when and with whom information is shared. There should be a package of measures be put into place to impede an *automatic* ongoing concentration of power (by information). Especially because after a society has decided to share information at a certain Level of Detail, with a certain direction in time and with a certain number of recipients, we expect it will be difficult to turn back the clock. For example: government agencies that are used to having energy usage information at their disposal, will probably object to that stream of information being stopped, since this would mean a reduction of their abilities to carry out public tasks in the area of inspection and fraud detection. In other words: we think removing privacy is easier than reinstating it.

The DOFIS-4SG model we have presented enables policy and decision makers to compare different designs of energy systems and markets with respect to aspects of

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exposing behavior and identity of parties Smart Grids. The comparison is not only with respect to aspects like ‘level of detail’ itself, but also with respect to the consequences of sharing information. We suspect that the model can be refined and extended and invite other researchers to do so. Currently, we are carrying out research on that refinement and in 2011 and beyond we hope to provide our research results.

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