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Towards a Hybrid Model for The Diffusion of Innovation in Energy Communities

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Abstract. The need for comprehensive models to simulate the diffusion of innovations in communities or social systems has become eminent. Existing models such as the Diffusion of Innovation expound how ideas, products, or innovations gain acceptance and spread over time. Other analogous models, such as the Transtheoretical Model also claim that people do not change behaviours quickly and decisively. Instead, they change in a continuous and cyclical process of internal decision-making. Although these two models are used to address adoption, it may be observed that one addresses it from a behavioural point of view while the other from the characteristics of the innovation perspective. In this study, we propose and develop a hybrid model based on these two. We expect that a composite model with enhanced attributes can be deployed as a decision support tool to enhance the diffusion of innovations particularly within energy communities. The study sought to conduct a structural and contextual analysis of these models hoping to find reasonable grounds for merging them.

Keywords: Transtheoretical model, Diffusion of innovation model, Behaviour change, Hybridization, Energy communities.

1 Introduction

It is generally acknowledged that the Earth's resources are depleting rapidly. The demand for these resources surpasses the planet's capability to supply, which has adverse effects on the environment, resulting in climate change. This phenomenon poses severe threats to societies due to overutilization of its natural resources. Social Innovations in the Energy Transition (SIET) is a novel and rapidly evolving concept that has been proposed to significantly contribute to the reduction in overexploitation, particularly, in energy related resources. It has been proposed in several studies including [1] to offer tools to support existing social structures at transforming their energy needs towards a sustainable one. Its impacts are expected to occur at the level of individual behaviour change and collective lifestyles in communities [1].

SIET, like many other emerging concepts, lacks a unified definition, however, from the perspectives of [1], "it represents social innovations that can contribute to the

energy transition.” The mentioned authors argued that such innovations may also entail the introduction of new energy related activities such as energy production, storage, distribution, consumption, as well as new energy-related behaviours.

Like many new innovations, SIET is likely to face some barriers towards its general acceptance and diffusion. Rogers in [2], maintained that behavioural barriers significantly affect the rate of adoption of many innovations. For instance, the rate of adoption for technologies such as the internet, per households, in the United States increased from 10% to 88.3% between 1993 and 2016, and for personal computers from 20.7% to 89.30% between 1992 and 2016 [3], a period spanning more than two decades for each technology. Other studies like [4] have also claimed that resistance to adoption is usually rooted in social and behavioural concepts like attitudes and value systems, therefore, solutions to diffusion could not only be technological, but also may include new ways of collaboration, decision-making, and mobilizing society [1]. Some studies that have also suggested and adopted the idea of collaboration to solve similar problems in energy communities are found in [5], [6], [7] and [8].

The objective of this study is to propose and develop a hybrid and multi-dimensional model that can be used as a decision support tool to equip community managers or innovators in managing or facilitating the general diffusion of innovations in communities. Although the proposed model could have a generic use, we expect to test it in subsequent studies using the diffusion of SIET as a case study. We consider a software simulation environment using Agent-based simulation techniques. This technique can help to represent the community, its members and the interaction between them using software agents in an agent-based model (ABM). An advantage of ABMs includes the facts that agents can be modelled to exhibit autonomous behaviours which may include autonomous decision making. They can be modelled to be proactive or goal-oriented, thus, having goals to achieve. Furthermore, these agents can be modelled to be cognitive/perceptive thus having a sense of awareness and finally, being adaptive to their environments.

The approach to the development of the hybrid model involves a structural and contextual analysis of two key models. These are: (a) the Diffusion of Innovation Model (DIM) and (b) the Transtheoretical Model (TTM). These models are selected because available literature reveals that (a) the TTM is one of the most widely applied models for behavioural studies, and (b) the DIM is also considered in literature as the leading model in the studies of diffusion. The hybrid model is expected to be novel in nature and characteristics. It is also expected to be multi-dimensional having a behavioural dimension and an innovation dimension simultaneously. We anticipate that the model can be useful for studying several cases of diffusion, particularly in cases that are similar to SIET, which is claimed in [1] as a multifaceted problem having dimensions that are technological, social, and behavioural. We call the hybrid model the “**Hybrid Transtheoretical and Diffusion of Innovation Model**” (HyTraIn model). The following research questions (RQs) are therefore used to guide the present study.

RQ-1. How do DIT and TTM models compare from both the contextual and structural perspectives?

RQ-3. Based on the observed contextual and structural similarities or differences, how can these models be hybridized into a single model?

2 Relationship with Applied Artificial Intelligence

Digital Twins (DT) are emerging to play essential roles in bridging the divide between physical and virtual spaces and helping to provide efficient, and intelligent services [9]. Its incorporation into the power grid could enable the integration of intelligence in the form of smart software agents which can provide optimum grid management in aspects such as autonomous control and decision-making [10]. By coupling these two spaces, preferences of physical entities such as households could be delegated to DTs [11] such that DT could make some decisions on behalf of the physical twin

This current study is a partial aspect of an ongoing Ph.D. research. In the study, we propose the idea of “Collaborative Networks of Influencers.” The study attempts to harness the influential roles played by community role-models or opinion leaders to facilitating the diffusion of SIET. Physical entities within the community could have a digital replica of themselves in the form of Cognitive Household Digital Twins (C-HDT). In [12], a Cognitive Digital Twins is described as a “digital reflection of the user, intended to make decisions and carry out tasks on the user’s behalf.” In this case, a C-HDT could be automated with a digital profile that reflects a set of attributes such as the physical twin’s value system, consumption preferences, sustainability choices, etc. These C-HDTs could be delegated to make decisions on behalf of their physical twin based on their digital profile. Such decision may include adoption of innovation and other behavioural issues that conforms to their predefined digital profiles. The idea of C-HDTs can help increase the level intelligence and smartness of households.

3 Related Literature

A comprehensive study in [1] provides an overview of SIET. It discusses its potential contribution to the energy transition and identifies its potential effects. Other studies, like [13], have argued that it is difficult to have a comprehensive definition for SIET due to the complexity and multidisciplinary nature of the concept. An European Commission (EC) funded project named SONNET, attempts to understand ways and conditions under which SIET can contribute to the commission’s strategy for clean the energy transition [14]. Another EC sponsored project called Social Innovation Modelling Approaches to Realizing Transition to Energy Efficiency and Sustainability (SMARTEES), is described in [15]. It aims at supporting the energy transition to improve policy design by developing alternative and robust policy pathways that foster citizen inclusion. COMETS (Collective Action Models for the Energy Transition and Social Innovation) [16], is also another EC projects intended to fill the knowledge gaps around citizen engagement in the energy transition.

Although several ideas and projects including the ones discussed above seek to address SIET, available literature reveals a gap in the availability and diversity of models to study diffusion of these concepts. In studies relating to diffusion, the DIM model in its unmodified form is often utilized. However, in its unmodified form, the DIM has limited capabilities to address diffusion from a multidimensional perspective. Therefore, this proposed model could be useful in complimenting existing ones and could help to advance knowledge in this area.

4 Analysis of Base Models

We hereby introduce some key terms that are used in the analysis. These are: (a) Decision Making Entity (DME) - the entity that is being influenced to either change behaviour or adopt an innovation, (b) Elements of Influence (EI) - the forces that drive change. These are pieces of information that are tailored strategically to suit the demands of a DME, and to induce in a change.

4.1 Diffusion of Innovation Model (DIM)

Figure 1 provides a structural representation of the DIM model [2]. This model expounds on how ideas, products, or innovations gain acceptance and spread through a social system. The model focuses on the innovation's characteristics such as its relative advantage, compatibility, complexity, trialability, and observability [2]. Some application of this model in the energy sector include studies such as [17]. The diagram shows the five distinct stages of the involved process and their sequence of progression. It also shows the transitions that connect the various stages. The communication channels represent the medium through which information is disseminated. Furthermore, the figure reveals two categories of stages. These are (a) covert actions stages and (b) overt actions stages. A covert action occurs internally within a DME, such as mental activities, which are often not physically visible to an observer. Overt actions, on the other hand, are actions that are physical and can be seen by an observer.

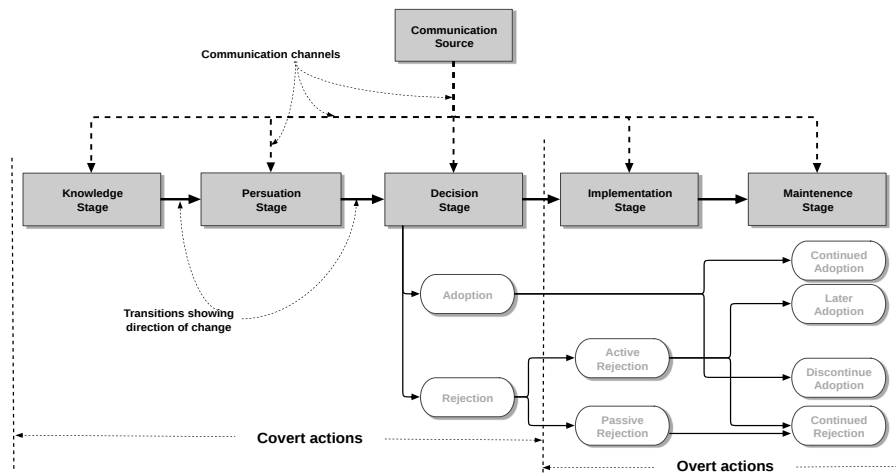


Fig. 1. A model of the diffusion of innovation before hybridization

Table 1 provides further details about the key attributes that characterize each stage in Figure 1. It also provides information about how different elements of influence are tailored to influence the DME at any stage of the mode.

Table 1. The various stages of the DIT, corresponding attributes and elements of influence [2]

Stages	Key attributes	Elements of influence
1 Knowledge	1.DME is aware of the existence of the innovation [2]. <i>Contextually, “awareness” is the central attribute of this stage</i>	<i>tailored to increase awareness and knowledge about the innovation</i>
2 Persuasion	1.DME seeks more information to evaluate the pros and cons of the innovation [2]. 2.DME seeks social reinforcement from near peers in making a final decision [2]. 3.DME forms either a favourable or unfavourable impression about the innovation [2]. <i>Contextually, “deliberations and social reinforcement” are central attributes of this stage. The DMEs deliberate whether to adopt or reject the innovation while seeking social reinforcement for their decision.</i>	<i>Usually tailored to increase knowledge about the innovation and also facilitate persuasion through social bonding, based on common values</i>
3 Decision	1.DMEs may try the innovation on a probationary basis to determine its usefulness in their situation. [2] 2.Trying the innovation reduces inherent uncertainty about its consequences [2]. 3.The outcome of this process is either a rejection or acceptance of the innovation [2]. <i>Contextually, “incipience” is the central attribute of this stage. gradual incipience of the desire either to adopt or reject the innovation is observed.</i>	<i>Usually tailored to facilitate the decision of the DME through easy access and engagement with the innovation. Technical information is also provided at this stage</i>
4 Implementation	1.DMEs actively participate in the innovation and seek more information such as: ▪ How to use the innovation effectively? ▪ What operational problems are likely to be encountered? ▪ Where to obtain the innovation? ▪ How to solve problems concerned with the innovation? [2] <i>Contextually, “commitment” is the central attribute of this stage. The DMEs actively commit themselves to innovation.</i>	<i>Usually tailored to aid in the form of “supportive messages” to the DME to strengthen decision and prevent “cognitive dissonance” from occurring</i>
5 Confirmation	1.DME seeks reinforcement of an innovation-decision. 2.DME may reverse the decision if exposed to conflicting messages about the innovation. <i>Contextually, “sustenance” is the central attribute of this stage. DMEs actively engage the behaviour and tries to avoid relapse</i>	<i>designed to provide supportive messages to the DME to strengthen decision and prevent “cognitive dissonance” from occurring</i>

4.2 The Transtheoretical Model (TTM)

Figure 2 is a structural representation of the TTM model. This model assumes that people do not change behaviours quickly and decisively, but rather, in a continuous and cyclical process of internal decision-making [18]. Some application of this model in the energy domain include [19]. The figure also shows the five distinct stages of the change process and their progression sequence from one stage to the other. It also shows the transitions that connect the various stages as well as the communication channels, covert actions stages and overt actions stages.

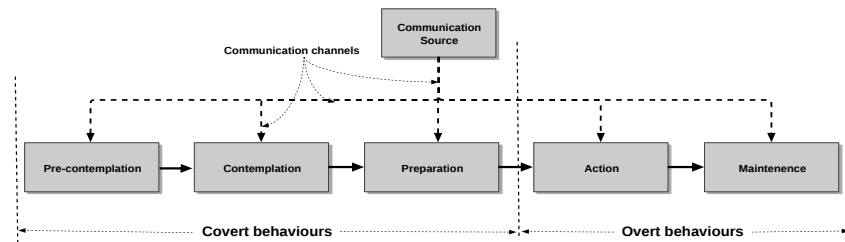


Fig. 2. A representation of the transtheoretical model before hybridization

Table 2 also provides further details about the key attributes that characterize each stage of the TTM. It also provides information about the various elements of influence.

Table 2. The various stages of the TTM, corresponding attributes and elements if influence [18]

Decision process	Key characteristics	Elements of influence
1. Pre-contemplation	DME has no intention to change behaviour in the foreseeable future. DME may lack knowledge of the effect of the problematic behaviour [18]. Contextually, “ignorance” is the central attribute of this stage. The DME is ignorant about their problematic state.	Usually tailored to provide information that could increase awareness and knowledge about the problem
2. Contemplation	DME is aware of the problem and is seriously thinking about overcoming it but has not yet committed to acting [18]. DME seeks social reinforcement from peers in making final decisions. Contextually, “deliberations and social reinforcement” are central attributes of this stage. DME deliberates about the behaviour change whilst seeking social reinforcement for their decision	Usually tailored to increase knowledge about the behaviour and also facilitate persuasion through social bonding and also based on common values
3. Preparation	DME is intending to take action immediately and report on small behavioural changes achieved [18]. Contextually, “incipience” is the central attribute of this stage. Incipience of the desired change is observed.	Tailored to aid decision of the DME and encourage small changes at a time

4 Action	DMEs modifies their behaviour, experiences, and/or environment to overcome the problematic behaviours [18]. Contextually, “commitment” is the central attribute of this stage. DMEs actively engage in the behaviour change and commits to sustaining it.	“supportive messages” to the DMEs to strengthen their decision and prevent “cognitive dissonance” from occurring
5 Maintenance	In this stage, the DME works hard to maintain the choice of behaviour, hoping to prevent relapse and consolidate the gains attained. [18]. Contextually, “sustenance” is the central attribute of this stage. DMEs actively engage the behaviour and tries to avoid relapse.	“supportive messages” to the DMEs to strengthen decision and prevent “cognitive dissonance” from occurring

4.3 Structural Comparison between DIT and TTM

Considering Figures 1 and 2, the following structural similarities are observed:

- The number of stages and transitions:** Each of the two models is comprised of five key stages connected by four transitions.
- Covert Stages:** The first three stages for both models are covert action stages.
- Overt Stages:** The last two stages for both models are overt action stages.
- Communication channels:** The communication channels for both models are similar. They both support centralized or decentralized sources of information. The observed structural similarities between the models form good grounds to propose a merger without compromising the structural integrity of both models.

4.4 Contextual Comparison, Hybridization, and Redefinition

From Tables 1 and 2, the following contextual similarities differences are observed:

- Pre-contemplation (TTM) and knowledge (DIT) stages.** These first two stages have opposing attributes. DMEs in the pre-contemplation stage are described as being ignorant of the existence of a problem. On the contrary, DMEs in the knowledge stage possess knowledge of the innovation. This, therefore, forms two opposing attributes. However, their respective elements of influence are contextually similar. They are both tailored to provide information that is aimed at increasing awareness and knowledge in the DMEs. Based on this contextual similarity, we propose the hybridization of these two stages into one (Figure 3). We call the hybrid stage the “*awareness stage*” and define it as the stage where a DME is provided with information about the “phenomenon” to increase knowledge and awareness about it. The phenomenon here could represent innovation or behaviour.
- Contemplation (TTM) and Persuasion (DIT) stages**
There is a common central attribute for these two stages. This can be described as “deliberations and social reinforcement.” It can further be observed that the elements of influence for both stages are usually tailored to increase knowledge and also facilitate social reinforcements. Social bonds, such as shared values are also vital here. This therefore suggests that by hybridizing these two stages, we could

tailor a common set of elements of influences that will focused on enhancing the deliberation process of the DME and also facilitate social reinforcement. We propose the hybridization of these two stages into one (Figure 3) and rename it as “**deliberation stage**”. *It can be defined as the stage where the DME has knowledge of the existence of the “phenomenon” and is contemplating adjustments towards probable engagement or disengagement with the phenomenon.* The adjustment may represent adoption or a change.

3. Preparation (TTM) and decision (DIT) stages

These two stages also have a common and central attribute. This is described as “incipience.” The elements of influences are tailored to aid the DME’s decision-making process. The elements of influence could also be focused on the encouragement of small changes at a time. This means that by hybridizing these two stages into one, the actions/activities that occur in this composite could be influenced by elements of influences that are tailored to enable decision making and encourage small changes. We thus propose the hybridization of these two stages into one (Figure 3) and rename it as “**incipient stage**,” *which can be defined as the stage where the DME begins to show interest in the “phenomenon” and initiates actions to experience the phenomenon. The DME will form an opinion that could be favourable or unfavourable towards it.*

4. Action (TTM) and implementation (DIT) stages

The central attributes in these two stages can be described as commitment. The elements of influence from these stages are tailored to reinforce or strengthen the commitment and decision of the DME and to prevent relapse. Again, we propose the hybridization of these two stages into one (Figure 3) and rename it as “**commitment stage**”. *It is defined as the stage where the DMEs actively engage themselves with the phenomenon and make environmental or personal modifications to sustain the phenomenon and prevent relapse.*

5. Maintenance (TTM) and Confirmation (DIT) stages.

Finally, the central attributes in these last two stages can be described as sustenance. The elements of influence are tailored to strengthen the DME’s decision and to prevent relapse or cognitive dissonance. We also propose the hybridization of these two stages into one (Figure 3) and rename it as “**sustenance stage**.” *This hybrid stage is defined as the stage where the DME actively works to sustain the phenomenon and tries to avoid/prevent relapse/cognitive dissonance from occurring.* Cognitive dissonance describes the mental state of discomfort that results from holding two conflicting beliefs, values, or attitudes. People tend to seek consistency in their attitudes and perceptions, so this conflict causes feelings of unease or discomfort and could affect the decision of the DME [20].

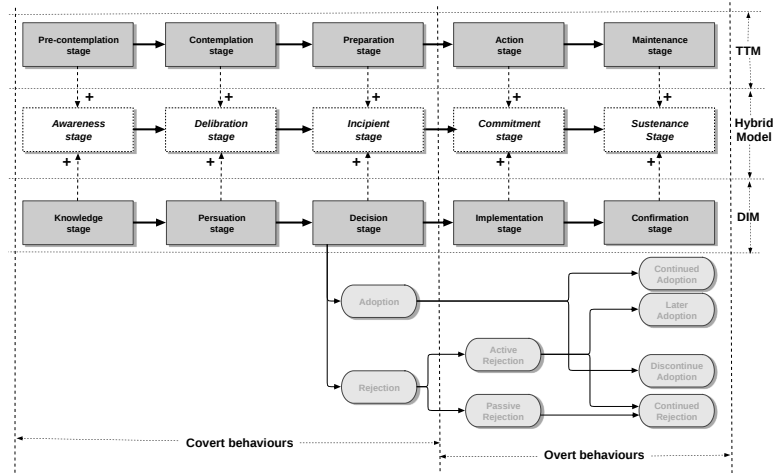


Fig. 3. The hybridization process of DIT and TTM models.

4.5 The Hybrid Transtheoretical and Diffusion of Innovation Model (HyTraIn)

Figure 4 shows the outcome of the hybridization process. It represents the final version of HyTrain model. It is essential to indicate here that the hybridization only occurred at the primary section of the HyTraIn model. The stages indicated as the secondary section was not hybridized. Therefore, their functions remained the same as the original DIT model. However, these stages need to be redefined so as to conform with the intent and purposes of the HyTraIn model. The redefinition is shown in table 3. Engagement here means that the DME gets involved with the phenomenon. Disengagement means the DME does not get involved with the phenomenon. In future implantation using the Anylogic simulation platforms, DMEs will be modelled as software agents and the various stage of the HyTraIn model shall be simulated as internal states of the DME. These internal states shall be modelled using charts. The transition between states will also be controlled using inbuilt transition triggers that are activated based on several signals such as condition, messages, timeout rates etc. The elements of influence will be modelled using system dynamics stock and flow blocks and the communication between DMEs will be achieved through inbuilt communication networks in Anylogic.

Table 3. Redefining the primary sections of the DIT model

Original stages	Redefined stages
Adoption	Engagement
Rejection	Disengagement
Active rejection	Active engagement
Passive rejection	Passive disengagement
Continued adoption	Continued engagement
Later adoption	Later engagement

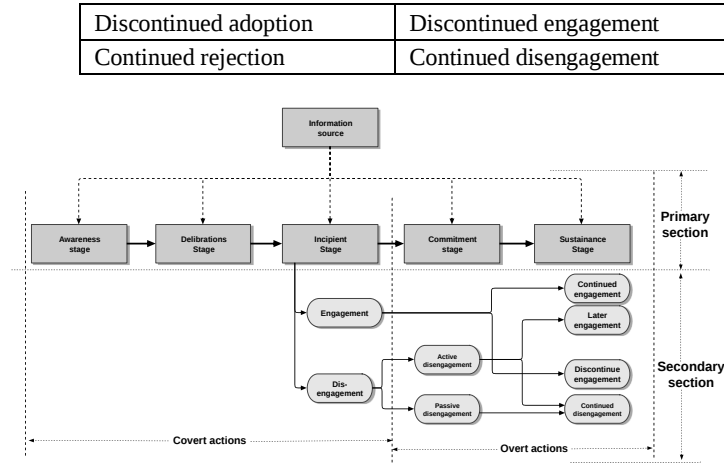


Fig. 4. The final HyTraIn model.

5 Demonstration of the Modelling Technique

Full implementation of this model shall be advanced in subsequent studies using a multi-method simulation approach. The method shall integrate system dynamics, agent-based, and discrete event simulation techniques in a single simulation platform called the Anylogic [21]. By adopting this approach, CHDTs shall be modelled as DMEs using software agents to represent them. The community shall also be modelled as constituting of several interconnected software agents using diverse network topologies to represent the communication channels for message passing. As a brief introduction to the modelling technique, we use Figure 5, DME-1 to represent a C-HDT. This CHDT as an example has a digital profile shown as comprising of 3 values and 3 attributes. The C-HDT also possess an input, a decision block and an output.

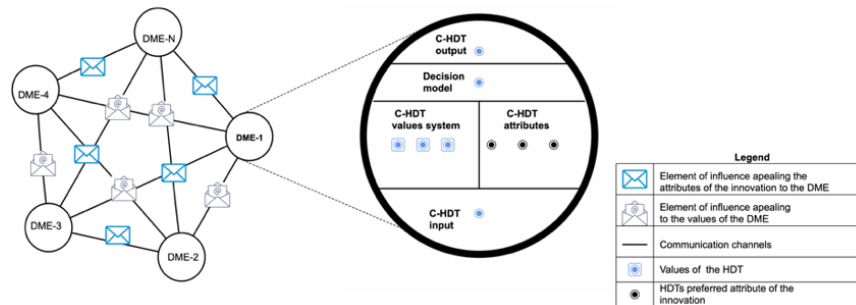


Fig. 5. A mesh network of interconnected software agents showing the exchange of elements of influences and digital profile of a C-HDT.

The impact of these messages on the C-HDT is modelled using a probability distribution function modelled as a *uniform distribution* (x, y) , where x is the minimum impact induced by the message and y the maximum. Since the distribution is a continuum and oscillates between these boundaries it could be used to simulate some dynamics in the degree of impact caused by these messages. The impact of these messages will trigger an internal behaviour in the C-HDT which can be visualized at the output as shown in figure 6. These internal behaviours are used to make decision within the decision block of the C-HDT. C-HDTs will only accept and consume compatible messages. Non compatible messages are rejected and cannot trigger any behaviour. A message is considered compatible if its content matches with any one of the predefined set of attributes for the recipient C-HDT. The cognitive capability of these C-HDTs is derived from their ability to recognize compatible messages from non-compatible ones. As the number of compatible messages increases, the magnitude of its oscillations also increases until the decision threshold is reached or exceeded. At this point the CHDT makes a decision. The types of messages to disseminate, time and frequency of dissemination shall be decided by a community manager in collaboration with the influencers. The community manager and the network of collaborators will adopt the hyTraIn model as the main decision support tool.

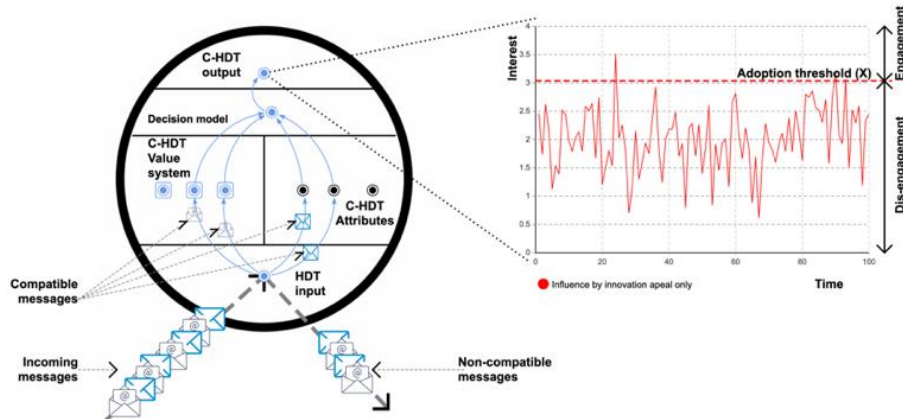


Fig. 6. A C-HDT showing incoming, compatible, and non-compatible messages.

6. Application of Concepts to Energy Communities

Delegation of deferrable loads (DDL) refers to the process whereby consumers/prosumers within a community accept to delegate the control of their household appliances such as dishwashers, tumble dryers and washing machines to an external entity such as an aggregator or a community manager for purposes of promoting sustainable consumption [5]. These appliances are often referred to as “deferrable loads” because users can defer or delay their preferred time of use to later periods without causing significant inconvenience to them.

The challenge with DDL is that it solely depends on the willingness of the user to

participate. Potential adopters are often faced with barriers such as perceived inconvenience, fear of losing comfort, or the fear of not being in control. DDL could therefore be considered a good example of SIET whose acceptance and diffusion can severely be hampered by these barriers which can be considered as a mix of social and behavioural concerns. By adopting the concepts discussed in this study, users could define their preferences relating to the DDL and delegate them to their C-HDTs. For example, a CHDT could accept a DDL proposal based on the level of flexibility offers.

Other attributes about DDL that could appeal to the value system of the C-HDT may include benefits to the user, benefits to the community, immediate impact on the environment, level of social inclusion and cohesion, etc. These DDL attributes could carefully be crafted into pieces of elements of influence and disseminated through existing communication channels in the form of messages. Our proposed C-HDTs, through their cognitive abilities, can identify attributes of DDL that suit their digital profiles and can decide to whether to engage or disengage.

7. Conclusion and Future Work

In this study, we have analysed the Diffusion of Innovation and Transtheoretical models' structural and contextual properties. Based on this analysis's outcome, we have proposed a hybrid model that encompasses the attributes of both models. We have partially illustrated the modelling approach and the modelling tools to be adopted for subsequent studies. The application of the proposed concepts in energy communities has also been discussed briefly. In future studies, we shall advance these ideas by integrating the HyTraIn model as a decision support tool for a group of collaborators. These collaborators (Collaborative Network of Influencers), using the HyTraIn model as a tool, will decide which elements of influence to disseminate, how and when to disseminate them, what level of impact is expected to be achieved, what level of impact is being achieved, when to transition and implement subsequent stages of the model, and when to repeat the cycle etc. It is expected that these ideas could help to facilitate the rate of adoption SIETs in communities.

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